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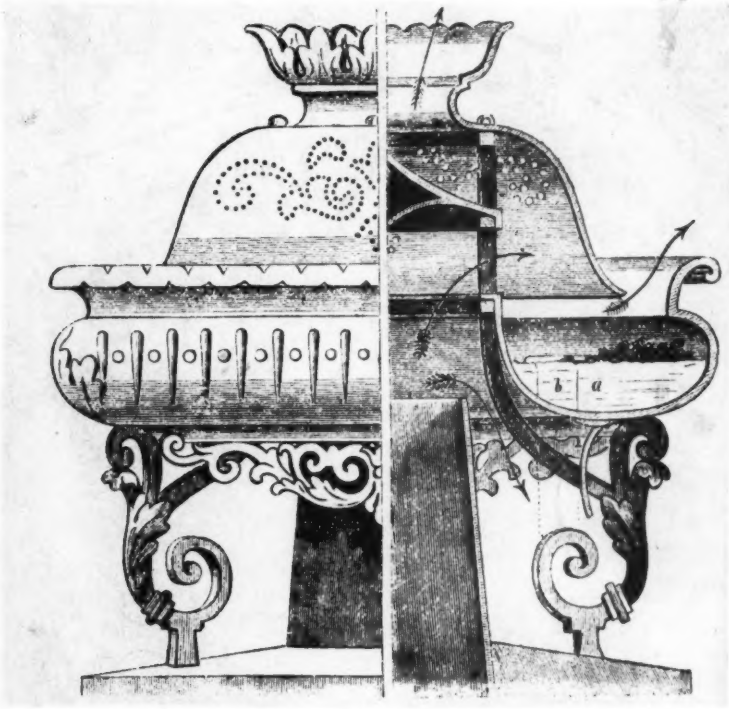
JOURNAL of the AIR POLLUTION CONTROL ASSOCIATION

SCIENCE & TECHNOLOGY

Founded 1907

STACKS

February 1958
Vol. 7, No. 4



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(See Page 289)

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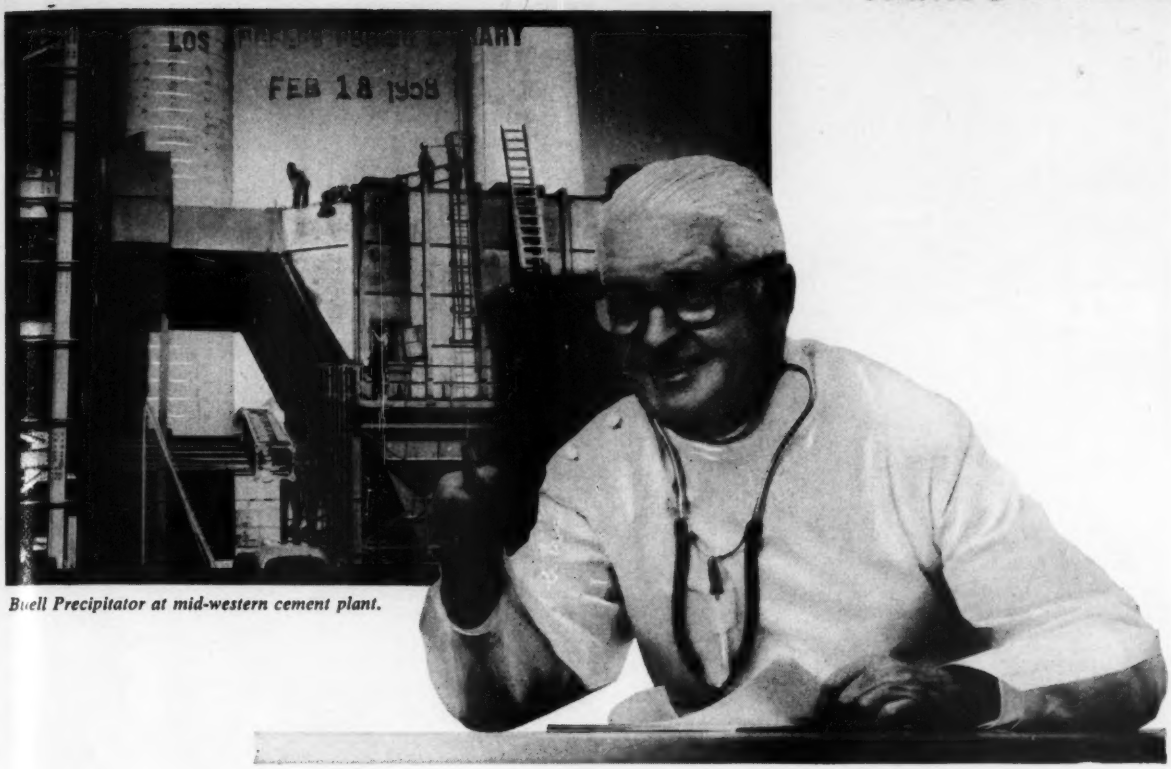

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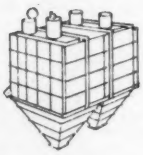

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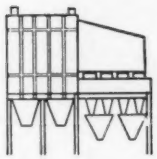

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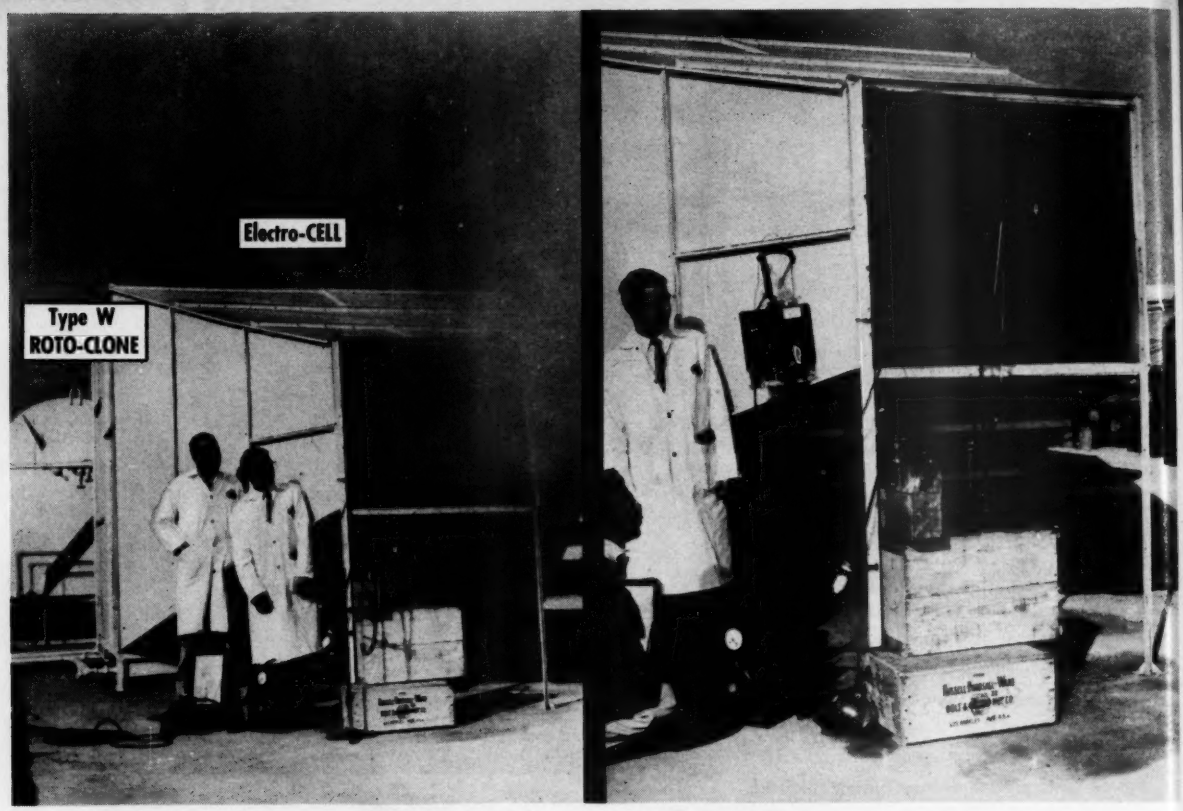

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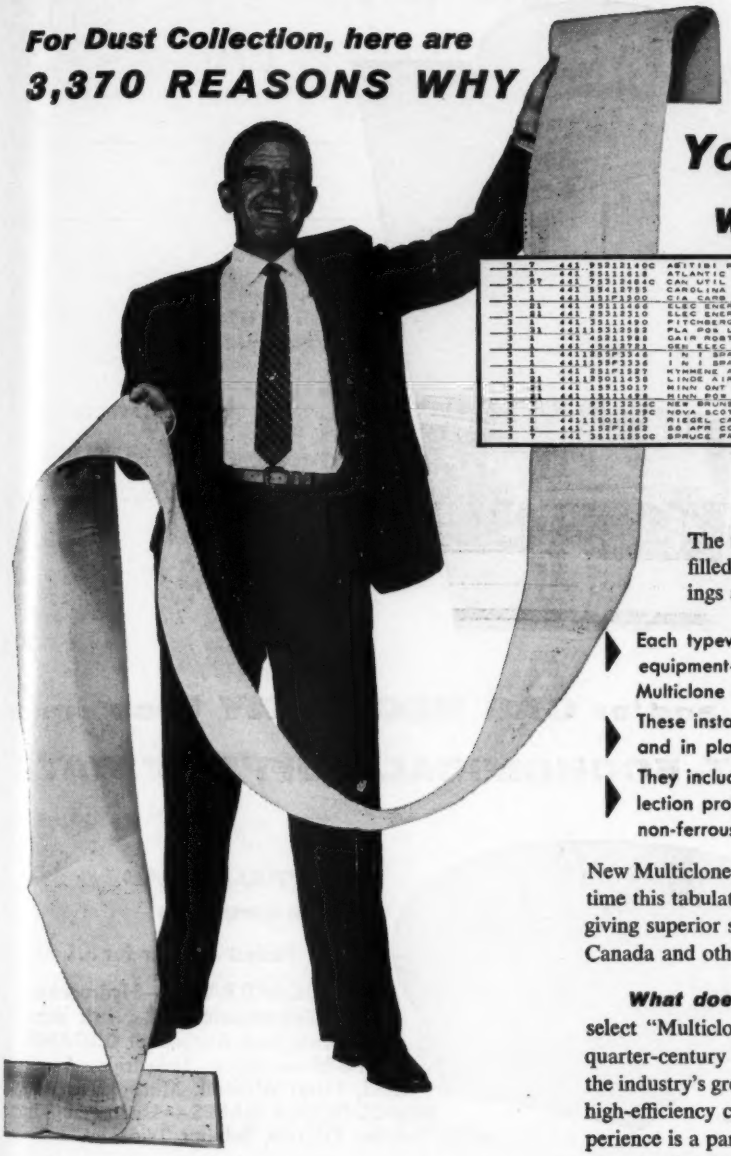

The tabulation sheet shown here is over 40 feet long, filled top to bottom with single-spaced typewriter listings as in the enlarged section above...

- Each typewritten line tabulates an installation of Multiclone equipment—an installation of from one to nine separate Multiclone units!
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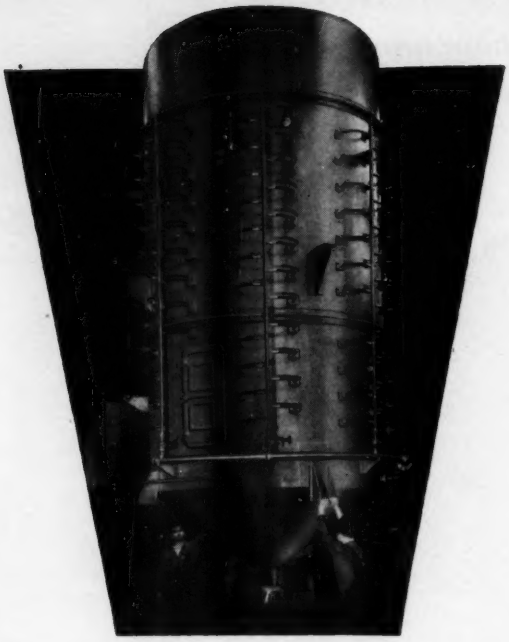

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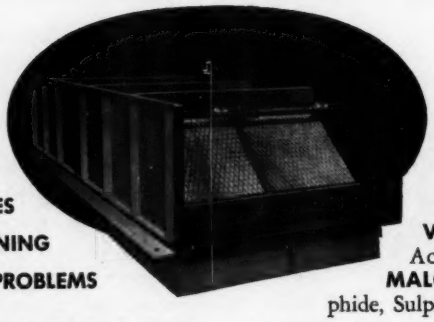

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JOURNAL OF THE AIR POLLUTION CONTROL ASSOCIATION

(Formerly "Air Repair")

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The Editor welcomes writers interested in air pollution problems and encourages them to use the pages of this journal for the expression of their opinions. But neither he nor the Association assumes responsibility for the validity of the opinions expressed herein.

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In Charlotte, North Carolina

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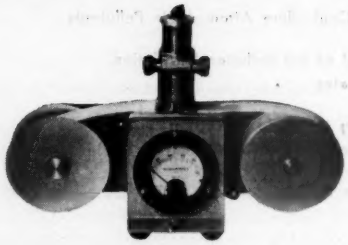
TO ANALYZE THE SPOTS, Research Appliance Company manufactures a Spot Evaluator with which spots are evaluated by measurement of light transmission.

Write for descriptive bulletins that give complete construction and performance details of both the samplers and the Spot Evaluator.



RESEARCH APPLIANCE COMPANY

Box 307 Allison Park, Pa.

Studies of Air Pollution Control By Southern California Edison Company*

A. J. HAAGEN-SMIT
California Institute of Technology
Pasadena, California

In recent years the unpleasant discovery was made that the air over our densely populated areas is not as unlimited as some of us had thought. While at one time all waste products could safely be disposed of by dispersal in the rivers or in the air, this is no longer true, and stringent regulations have been made after several serious accidents had occurred. The best known are those of London, Donora, and Poza Rico, Mexico. No such accidents have been reported from smog-plagued Los Angeles, and extensive studies by epidemiologists have not been able to produce evidence that permanent damage to the health occurs in this area. Nevertheless, the frequent visitation by the eye-irritating smog cloud has resulted in the adoption of a number of relief measures, some based on extensive research and others on experience gained in other areas.

Research has shown that the major cause of Los Angeles smog difficulties lies in the release of large quantities of organic material, mostly from automobiles[1]. These compounds are photochemically oxidized in the air by simultaneously emitted oxides of nitrogen, and these reactions give rise to eye-irritating and plant-damaging substances. An interesting side reaction during this oxidation produces relatively high concentrations of ozone which attacks rubber tires and is largely responsible for the so-called *oxidant* effect of Los Angeles smog, currently used as an objective measurement of smog severity[2] [3]. The oxidant, being the result of a photochemical phenomenon, rises in the daytime and is low in the evening and during the night. These findings have resulted in extensive recovery measures in the oil industry, and in research on better combustion in the automobile. A practical solution of this problem, and also the control of oxides of nitrogen, is still far away.

Based on experience gained in other areas, a great deal of stress has been laid on the control of directly visible pollution, dust and fume-producing sources. As a result, dustfall has been reduced to half its former value; open dumps, foundries, steel mills and many sources of readily detectable, objectionable fumes have been corrected.

Careful investigations were made of industrial and municipal fuel-burning installations which were known to contribute considerably to air pollution in other areas. The problem in Los Angeles is, however, completely different, and a comparison with Eastern cities and their approach to clean air is rather useless, for no coal is burned in this area at all. Nearly all the power generated in this area is derived from petroleum products — fuel oil, gas and gasoline.

The power plant engineer is an expert in obtaining the maximum efficiency from his fuel. Routine industrial Orsat analyses are not able to detect any carbon monoxide; infrared spectrofotometric methods revealed the presence of only a few ppm. of carbon monoxide. The concentration of hydrocarbons, aldehydes and organic acids do not exceed, as a rule 20 ppm. We may therefore, conclude that the combustion is, for all practical purposes, 100% complete. A constant check on this is part of the regular routine in the station. Moreover, smoke density is continuously measured in the stack, and this information is recorded in the control room. Also, the correct burning of the fuel is checked by means of a television set looking into the furnace. Under these ideal conditions, it would be expected that the stack gas would be wholly composed of carbon dioxide and water, the unused oxygen, and all the nitrogen and other normal components of air. Unfortunately, this view is rather optimistic, for we are not dealing with pure hydrocarbons in fuel, but with a product which contains, because of its origin, organic sulfur and nitrogen compounds. The inorganic materials, also present in the oil, give rise to a dust consisting, for the most part, of oxides of iron, nickel and vanadium.

TABLE I

Analysis of Stack Gas*	
Gas Velocity, F./Sec.	22
Gas Temperature, Deg. F.	688
Insoluble Solids, Gr./SCF	0.055
lb./Hr.	0.52
Soluble Solids, Gr./SCF	0.119
lb./Hr.	1.13
Water, %	9.4
Sulfur Trioxide, SO_3, ppm.	21.3
Sulfur Dioxide, SO_2, ppm.	945
Oxides of Nitrogen, NO_2, ppm.	670
ORSAT ANALYSIS	
CO_2, %	14.6
O_2, %	3.0
CO, %	0.0
N_2, %	82.4

*Truesdail Laboratories Test No. 3, April 16, 1956, p. 2.

During the combustion, organically bound sulfur is oxidized completely to oxides of sulfur, mostly sulfur dioxide, with a small amount of the trioxide. Depending on the nature of the nitrogen compounds, small amounts of oxides of nitrogen may be formed in addition to those produced in the fixation of atmospheric nitrogen at the high temperatures reached in the flame. A typical analysis of stack gas from a fuel-oil burning plant (Southern California Edison Company, El Segundo Steam Station) is shown in Table I. The Los Angeles County Air Pollution Control District has made estimates of the total quantities of all the various pollutants from the various sources in the Los Angeles Basin. These estimates are a matter of public record. Table II lists the relative contribution of dif-

*Presented at the 50th Annual Meeting of the Air Pollution Control Association held at St. Louis, Mo., June 2-6, 1957.

TABLE II

Pollutants (Tons/Day) Emitted to the Atmosphere In Los Angeles County from Combustion Processes

Fuel	Organics	Oxides of Nitrogen (as NO_2)	Oxides of Sulfur (as SO_2)	Aerosols, Dust
Gas	20	100	100	10
Oil	10	200	300	30
Gasoline	1,000	400	40	30
Refuse	100	20	20	100
Total combustion	1,000	700	500	200
Total emissions	2,000	700	600	200

ferent fuels to the emissions from combustion sources alone.

The estimates in Table II have been rounded off, because it is rare when greater accuracy than 20 to 30% is obtained. This relatively large uncertainty is not a reflection on the quality of the work, but is inherent to this type of analysis. Especially in the case of computations of emissions of millions of automobiles and incinerators in all their variety, their different stages of disintegration, and manner of operation, it is practically impossible to obtain a satisfactory average. Then we introduce then, in addition, different weather conditions, sampling and analytical difficulties, to mention only a few more variables, it is clear that a figure such as the emission from gasoline combustion, indicated as 400 tons of NO_2 and 1200 tons of organics/day, must be accepted with considerable reservation. The hydrocarbon figure is probably reasonably accurate. There are differences of opinion on the quantity of oxides of nitrogen released by the automobile, and some maintain that the emission is nearly 800 tons/day. In the table, the lower figure has been chosen, which is already considerably higher than might be expected from the burning of 12,000 tons of gasoline/day.

Large scale testing of automobiles in the Los Angeles River bed has just been completed, and more definite figures will be available in the near future. It is not expected that the refinement in the analysis will cause a revision in the policy of air pollution control, based on obtaining the maximum efficiency in combustion of all kinds — gas, oil, gasoline or refuse. It does, however, emphasize the importance of the control of oxides of nitrogen in power sources other than automobiles.

Where methods of control are available, their application will be quite expensive in initial cost as well as maintenance, and it is therefore necessary to discuss first the question why emissions of power plant stacks should be controlled. In attempting to answer this question, it is well to distinguish here between local and widespread effects.

While there is no debate about the necessity of controlling such nuisance effects, there is considerable difference of opinion on the need for control when no physiological effects are noticed on plants or animals. This is the case in the Los Angeles area, where complete lack of plant damage shows that the SO_2 content is less than 0.2 or 0.3 ppm. Chemical methods tend to confirm these low values, although it should be realized that most SO_2 measurements made in the Los Angeles area are based on conductivity measurements which are easily interfered with by other electrolytes occurring in this area. The uncertainty of the analytical results is ever greater in the determination of sulfur trioxide, or rather, sulfuric acid. There is no indication that there is any free sulfuric acid in the Los Angeles atmosphere, and any sulfate found was in bound form, either as calcium sulfate or ammonium sulfate, both harmless substances.

The investigations of Johnstone and Gerhard[4] have shown that the oxidation of SO_2 to SO_3 is quite slow, and in laboratory experiments it was shown that during a 24-hr. period only ½% of the SO_2 is converted to sulfuric acid. The authors come to the conclusion that the gas phase oxidation of sulfur dioxide of naturally polluted atmospheres in natural sunlight would not be significant in effectively reducing the visibility, since it would require approximately 100 hr. of noon sunlight to reduce the visibility to one mile. For those living in other parts of the United States, this statement may do away with any suspicion that SO_2 has anything to do with a decrease in visibility. For the average Los Angeles inhabitant, used to panoramic view of dozens of miles, Johnstone's arguments are not so convincing.

Recent investigations have directed the attention to the strong photochemical oxidizing effects of the oxides of nitrogen, and it has been shown that, in the photochemical oxidation of organic material under the influence of these oxides, aerosols are formed which are believed to be mainly responsible for the dense haze which accompanies the eye-irritating cloud.

It is suspected that sulfur dioxide is also subject to an accelerated oxidation. Although this acceleration could not be established for the reaction in gas phase, there is a distinct possibility that more rapid oxidation may take place in liquid phase reactions in fog droplets, or in a combustion of gas phase and liquid phase reactions at high humidity, whereby the presence of metal oxides may exercise a catalytic effect. In speculations of this kind, we should also take into account that the concentrations of SO_2 and NO_2 at the exit of the stack are several thousand times higher than at some distance away. Some conversion does take place at these higher concentrations, a fact which is familiar to any one who has made attempts to determine accurately the concentration of SO_2 and SO_3 in exhaust gases.

It is well known that the appearance of the plume varies greatly with atmospheric conditions, especially with high humidity and low temperature. Plume formation due to the presence of SO_3 is noticeable at concentrations of SO_3 above 20 ppm. The concentration of SO_3 measured in the flue gas of the El Segundo Station under ordinary conditions represents a borderline case. At times of high humidity, or low temperature, the plume is more pronounced than on dry and hot days, and on those hot, dry days the visible plume is probably caused, for the most part, by inorganic dust. These considerations are, of course, of interest to any one who installs corrective equipment. If the plume is caused by a conversion of SO_2 into SO_3, the removal of the sulfur trioxide is indicated. On the other hand, if dust is the major cause, electrostatic precipitation would be the method of choice. At present, the opinions are divided on this subject, and while this question remains undecided, both controls will have to be considered.

To study the removal of dust and sulfur trioxide, a Western Precipitation pilot installation has been in operation at the Redondo Steam Station, and more recently, a more refined unit of the same type was built at the El Segundo Station of the Edison Company to obtain data on the efficiency of collections at higher flow rates. An APRA precipitation unit, operating at a temperature of 700°F., is being tested at El Segundo.

Studies on the control of the emissions of oxides of sulfur and nitrogen by the electrostatic precipitator units show that dust and aerosol particles are collected, and gases such as the oxides of sulfur and nitrogen are not removed. There is some removal of sulfur trioxide, or sulfuric acid, and its concentration is reduced to 10-20 ppm., or about half of its original value. There is reason to believe that, after installation of full scale units of this type, the plume will have largely disappeared.

It is not expected that the removal of dust and sulfur trioxides from power plant emissions will have a noticeable effect on the smog conditions in general in the Los Angeles basin. Attempts are therefore made to combine the installation of dust removal equipment with means of reducing the sulfur oxides, and especially, the oxides of nitrogen which are known to be essential components in smog formation.

Control of Emission of Oxides of Sulfur

Processes have been developed in the past which reduce sulfur oxides occurring in stack gases at concentrations of several thousand ppm. to about one thousand ppm. In the burning of oil with low sulfur content, sulfur dioxide concentration in the stack gas is already down to the thousand ppm. level, or lower. There is, at present, no satisfactory process which could handle economically the large quantity of gas of the order of half a million cfm. and reduce the sulfur dioxide concentration appreciably. The same is true for the removal of oxides of nitrogen. Processes are known for the control of these gases in nitric acid plants, but here again, the concentrations are many times higher than we find in flue gases of Los Angeles power plants.

There are several approaches to the problem of reducing the sulfur dioxide content of stack effluents:

(1) Use of gas, or fuel with lower sulfur content.
(2) Scrubbing of exhaust gases with *(a)* liquids, and *(b)* solids.
(3) Adsorption processes.
(4) Chemical conversions, and coupling with processes 2 or 3.

The Edison Company uses the maximum quantity of gas available, but the use of gas is unfortunately limited through its supply, and unless heroic measures are taken to increase importation of additional supplies, this shortage will be even more severe in coming years when more power is needed. The removal of sulfur from fuel is expensive, and would run into an increase in the fuel bill of several million dollars/year. The sulfur is present in complex ring systems and cannot be removed simply by washing with alkali.

The oil industry has been trying for years to break the heavy fuel oil to more valuable volatile products, but has not yet succeeded in doing this in an economically feasible manner. It is conceivable that a hydrogenation and special kinds of cracking processes could furnish more volatile fuel from which the sulfur has been removed as hydrogen sulfide. Any one of these processes will increase the cost of power considerably.

Scrubbing methods have been applied on large power plants in England along the Thames River. In the Battersea effluent process, SO_2 is removed by scrubbing with very large quantities of slightly alkaline river water. In the Howden I.C.I. non-effluent process the gas is scrubbed with a water slurry of lime or chalk. The resultant calcium sulfate, is removed by sedimentation and filtration, and is discarded. One of the objections to any scrubbing process is the cooling of the gases. Even though the gases are discharged from tall stacks they fall to the ground from time to time near the power station. This results in a nuisance, according to reports from England, where 2 stations are equipped with scrubbing devices. In order to prevent local complaints, it is necessary to remove almost completely both the obnoxious gases, SO_2 as well as NO_2, or reheat the flue gases before they leave the stack.

Other scrubbing processes use ammonia in ammonium sulfite with the intention of producing some usable product in the form of ammonium sulfate or sulfur dioxide or sulfuric acid. Aqueous ammonia solutions are being used by the Olin Matheson Chemical Corporation for the removal of sulfur dioxide, and it is claimed that one stage scrubbing will reduce the concentration of SO_2 in flue gas to 800 ppm.; a second scrubbing brings the concentration down to 300 ppm.

In the Fulham-Simon-Carves Ammonia Process, gases are scrubbed with a concentrated solution of ammonium salts (gas Liquor), ammonia being added at a rate corresponding to that of the absorption of oxides of sulfur. Oxidation of sulfur dioxide to the trioxide was encouraged through the addition of iron hydroxide and air. Even with low incoming gas concentrations of 500 ppm., reduction in concentration to 30 ppm. was accomplished.

Wet scrubbing with organic solvents, such as xylidine has been considered and is similar to the Gerbitol process whereby H_2S is removed from refinery wastes with diethanolamine and similar basic solvents. In principle, the method can be applied to the removal of SO_2. The low concentration of the SO_2 and losses in solvents through the large volume of inert gas to be treated are not encouraging.

In general, the wet scrubbing processes do not seem too promising after the experience in London. The cost seems rather prohibitive when operating with low SO_2 concentrations. A cost estimate has been made by the U. S. Bureau of Mines[5] for the coal industry, and the table on the following page gives the estimated costs of 3 different processes, based on an assumed capacity of 20 million SCF/Hr., equivalent to 475,000 tons of coal/year. Annual operating costs are estimated for cases with and without the formation of saleable by-products.

Dry scrubbing is generally not regarded as economical because of poor penetration of the gases into the chemical agent or adsorbant. On the other hand, a selective removal of SO_2 and NO_2 by a solid has the advantage that cooling of the gases as in a wet scrubber may be prevented. The combination with alkaline chemicals is probably limited to the use of lime. In this respect, a combination of the waste products of cement plants and power plants deserves consideration, when the location of the plants is favorable and means of disposing of the combined waste products are available. This solution is,

Process	Capital Cost	Annual Operating Cost (Dollars/Ton of Coal)	
		No Credit	Credit
Limestone	$1,431,450	$1.23	$1.23
Ammonia	2,855,500	3.00	1.40
Sodium Sulfite	2,176,650	1.99	1.79

of course, only feasible in a few selected areas and other means have to be found which are more generally applicable.

A modification of the dry scrubbing method consists in the introduction of potential alkaline reagents, such as chalk, dolomite or lime in the fuel bed at different locations. Some experiments along these lines are being conducted at the Southern California Edison Company El Segundo Station, mainly for the purpose of reducing the amount of sulfur trioxide. These methods are not expected to reduce materially the SO_2 or NO_x concentration. One disadvantage of the method is the addition of several tons of dust, which adds to the required size of the precipitators. A possible advantage may be that the stack gases are somewhat less corrosive.

Several of the experimentally tested methods of SO_2 control have been described in Mallette's *Problems and Control of Air Pollution.*[6]

Adsorption Methods

Adsorption on nonreactive media such as charcoal, silica and exchange resins opens the possibility of regenerating the adsorbed gases in more concentrated form by a simple process such as heating, treatment with steam or elution with aqueous ammonia solutions. Bench experiments at the Southern California Edison Company El Segundo Station have shown that activated charcoal adsorbs considerable quantities of sulfur as well as nitrogen oxides, even at temperatures of 150°F. The quantities adsorbed on different kinds of charcoal are listed in Table III. Recovery was accomplished by heating to 500-700°F., whereby the SO_2 is removed in concentrated form. After the adsorption and description the charcoal can be used again. This quality, very important for a successful technical application, is being investigated.

It has been observed that the oxides of nitrogen are adsorbed ahead of the sulfur dioxide and that they are gradually desorbed when the well defined SO_2 adsorption boundary moves forward to the end of the column. Both oxides are concentrated in this process and existing methods of recovery could be applied without difficulty.

A process of this type is no doubt expensive. One of the best grades of charcoal adsorbs/gr. of charcoal, all sulfur dioxide from 2 ft.^{3} of flue gas, which means that at a rate of half a million ft.^{3}/min. of flue gas, one needs every minute 2½ tons of charcoal. The possibility exists of accomplishing the adsorption in a flowing bed, as is being done for the separation of hydrocarbons by the petroleum industry. The conditions for sulfur dioxide adsorption are more favorable than for hydrocarbons because of the large quantities of SO_2 adsorbed. Some of the charcoals used adsorb as high as 30% of their weight of sulfur dioxide at room temperature and 10% at 150°F., notwithstanding the high water and CO_2 concentrations. An additional advantage is the complete absence in flue gases of gums which have given trouble in the technical application of adsorption methods.

Chemical Conversions

Many attempts have been made to convert sulfur dioxide into forms which would be easier to remove from the gas stream. Reduction to hydrogen sulfide and sulfur, as well as oxidation to sulfuric acid have been carried out. Because of the low concentration of sulfur dioxide in flue gas, coupled with the presence of excess air, reduction methods seem not very promising. Oxidation to sulfuric acid, on the other hand, is carried out in the wet scrubbing Fulham-Simon-Carves process, but can also be accomplished by catalytic action of vanadium pentoxide.

The Control of Oxides of Nitrogen

In general, the oxides of nitrogen are more difficult to remove than the SO_2. Scrubbing with alkaline reagent removes only a part of the oxides of nitrogen, even though strong bases are used. The major portion of the oxides of nitrogen originate in the fixation of atmospheric nitrogen at the high temperatures of combustion. The rapid cooling of the gases is an important factor in the relatively high nitrogen oxide content of the stack effluent, since rapid cooling prevents a shift of the equilibrium to the lower NO concentrations normally found at lower temperatures. It follows that a change in cooling rate or combustion temperature through changes in burner design or in the furnaces themselves might effect a considerable reduction in the nitrogen oxides formed.

There is also the possibility of decomposing the NO into nitrogen and oxygen, or of oxidizing it to the nitric acid stage. Both might be accomplished catalytically. After the oxidation, the strong acid character of nitric acid would make removal by

TABLE III

Adsorption of Sulfur Dioxide on Charcoal

Charcoal*	Adsorption Temperature (°F.)	Flow Rate Ft.^{3}/min.	Mgs. SO_2/g. Charcoal
A	77	0.1	153
	300	0.1	19
B	77	0.1	285
	150	0.1	127
	300	0.1	29
C	77	0.1	54
	300	0.1	30
D	77	0.1	244
	150	0.1	82
	220	0.1	62
E	77	0.1	143
F	77	0.1	253
G	77	0.1	225

*"A", "B", "C", *etc.*, are code letters for the different charcoals tested.

scrubbing with alkaline reagent a possibility, although the same objection can be raised against wet scrubbing as in the case of SO_2. Chemical binding with lime is also a possibility, but will be dependent on the presence of cement factories. While work along these lines is going on, attempts are being made to eliminate the remaining oxides of nitrogen by chemical means. The most attractive process would consist in the decomposition to nitrogen and oxygen, and catalytic agents are being sought which will accomplish this.

Another approach is based on oxidizing the oxides to nitric acid, which then could be removed by scrubbing processes. The simultaneous presence of sulfur dioxide suggests the possibility of using reactions similar to those in the lead chamber process for making sulfuric acid. There are indications that catalytic agents can be used to convert both sulfur and nitrogen oxides to the higher oxides when excess air is present.

It is clear from the foregoing that no matter which process will ultimately be developed, the cost will be high. The return on valuable by-products will be small, and even doubtful when all fuel burners begin to recover sulfur and nitrogen oxides. There is also no doubt that there will be a demand for ever-increasing completeness of the control, since the end of the population increase is nowhere in sight.

Such situations demand extraordinary methods, and one of these is the decision of all power generating agencies to work together to exchange information on anything that may lead to a solution to the problem of stack gas control. This decision is comparable to one taken several years ago in Pittsburgh when a council was formed by a group of people who had only one goal in mind — to clean up Pittsburgh. Forgetting private interests, these representatives of different industries prepared and carried out a campaign in air pollution control, which resulted in a marked improvement in the Pittsburgh atmosphere.

In Los Angeles, the Joint Research Council on Power Plant Air Pollution Control has been operating quietly since March of 1956. Its members include representatives from all the power companies in this area, together with delegates from the Los Angeles County Air Pollution Control District. These men meet regularly to exchange information on the research program now under way, and this in itself, is a big step in the right direction.

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Disposal Of Gaseous Effluents From Nuclear Power Plants*

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Effluents from nuclear power plants differ from general industrial wastes because of one major factor; namely, the possibility of their containing radioactivity. This is the result of the inherent radioactivity of the reactor fuel and of the fission products formed by splitting of these fuel atoms. The effluents could also contain substances which become radioactive through exposure to the neutron flux of the reactor. In view of the characteristics and potential of the radioactivity as an environmental contaminant and a biological hazard, particularly for those isotopes with long effective life, the safe handling and ultimate disposal of wastes from the nuclear power installations are integral and important aspects of their designs and operations. More money probably has been spent and more scientific and technological effort concentrated on operations, as well as on research and development with regard to this industrial waste, than on any other industrial contaminant we have known.

Virtually all activity in the field of atomic energy is currently under the administration of governmental agencies or contractors. The success of their efforts is attested by the few reports of injury and damage set forth in the recent report *Radiation Safety and Major Activities in the Atomic Energy Programs*[1]. Radiation exposure records of more than nine years of routine operations by 32 principal contractors of the Atomic Energy Commission show that 99.4% of nearly 200,000 workers monitored received less than ⅓ of the amount of radiation exposure deemed acceptable. Accident records show that in the past 11 years, there have been only 16 radiation accidents of contractors' employees, 2 of which caused 2 deaths in 1945 and 1946.

* Presented at the 50th Annual Meeting of the Air Pollution Control Association held at St. Louis, Mo., June 2-6, 1957.

The amounts of fission products on a weight basis formed in a reactor are really quite small. For example, a 400 thermal megawatt reactor, capable of producing some 100,000 kw. of electricity, will form about 1 lb. of fission products/day.

Air pollution problems associated with nuclear power plants could arise from contamination of the environmental atmosphere with these radioactive materials if they are not controlled. The maximum permissible concentrations of radioactive material in the atmosphere have been established by the National Committee of Radiation Protection of the National Bureau of Standards for the protection of personnel and the general public.[2, 3] Federal and state agencies concerned with the use and disposal of radioactive materials, such as the Department of Commerce, Labor and Public Health, as well as the U.S. Atomic Energy Commission, have all set up regulations which limit the exposure of personnel to radiation, and concentrations of radioactive material which may be discharged into air and water, and the ultimate disposal of these radioactive wastes. Their exposure and concentration limits are essentially the same as those established by the National Committee of Radiation Protection. The regulations must be followed in the handling of all radioactive materials subject to the licensing authority of the U.S. AEC.[4]

Sources of Radioactivity

In addition to nuclear reactors, a nuclear power industry requires chemical plants for reprocessing spent reactor fuels, with waste disposal systems and other facilities. The fission products generated by operation of the nuclear reactor accumulate with time within it, resulting in a reduction of the fission reaction rate, soon requiring separation of these products from the fuel. A second reason for reprocessing fuel from many reactors when it is only partially burned up is that the extreme intensity of the radiation may damage the solid fuel elements by causing intolerable dimensional changes. The fuel is then processed for reuse of the fissile materials while the fission products must be diverted for disposal or recovered for use as radiation sources. The chemical reprocessing and waste disposal facilities, unless subjected to the same stringent control imposed on the reactor plant, could be sources of air or water pollution from causes similar to those observed in any other chemical plant or disposal facility.

Air Contaminants

Concentrations of radioactive substances may be hazardous to people exposed within the range of actions of the radiations and particles emitted. The principal potential hazard of nuclear power plants is associated with the escape of fission products. These fragments of the original uranium or plutonium atoms are radioactive and decay with the release of energy and particles to daughter atoms which may also be radioactive. Such radioactive chains of fission products include over 200 isotopes with mass numbers 72 through 161. About 40% of these fission products exist in the gaseous form and decay to stable, non-volatile, non-radioactive elements.

Radioactive air contaminants may be grouped into 4 general classifications which include:

(1) Volatile fission products,
(2) Non-volatile fission products,
(3) Particulate dispersions of fuel materials, and
(4) Induced activity of gaseous and/or particulate components of exposed air.

These vary in importance as hazards, depending upon the reactor type and the probability of accidental release. They are discussed in the following:

(1) Volatile Fission Products usually include the isotopes of the halogens bromine and iodine, and the noble gases xenon and krypton. At elevated temperatures others, including rubidium, cesium, antimony, tellurium, etc., may escape from the fuel. Many of the daughter products, while non-gaseous, are radioactive and must be taken into account since they may be created by transmutation while in an effluent stream. Being electrically charged atoms, the solid daughters can affix themselves to dust partciles of the air and on solid surfaces. The particulates may be controlled by filtration. A gaseous, volatile fission product of major concern is iodine-131 which (a) is produced in relatively large amounts, (b) has a relatively long half-life of 8 days, and (c) when inhaled, concentrates in the thyroid to produce an intensified effect. The maximum permissible concentration (MPCa) in air for continuous exposure of humans to this isotope is 3×10^{-10} microcuries/cubic centimeter (μc/cc.). (A curie is a standard unit of radioactivity defined as the quantity of any radioactive nuclide in which the number of disintegrations/sec. is 3.7×10^{10}.) When this maximum permissible concentration of iodine-131 is expressed as atom parts/part of air, an inconceivably small number is found: namely, one part of iodine-131 to 10^{18} parts of air. Fortunately, iodine can be removed readily from process off-gases by chemical interactions.

Radioactive xenon and krypton in the air produce principally an external, rather than an internal hazard. The quantities of xenon and krypton produced in a commercial scale power reactor are many times too great for immediate discharge to the atmosphere, even using the most efficient means for dispersal. Measures must be employed for the retention of these highly radioactive gases until they have decayed sufficiently for release. After a 120-day decay period, the only radioactive isotope of xenon and krypton remaining in any significant quantity is krypton-85. However, the quantity of krypton-85 is small enough that safe disposal from most reactor power plants can be accomplished by dispersion into the atmosphere from a tall stack. This radioactive isotope could also be recovered for use as a beta-ray radiation source.

(2) Non-Volatile Fission Products include all but the noble gases and are encountered as particulates in effluent gaseous streams. Halogen compounds may be in this group also. These particles may become airborne as a result of processes which allow the escape of finely divided solids, generated mists, sprays, or droplets. The non-volatile fission products include some of the most significant contaminants. One of these is strontium-90 with its active daughter, yttrium-90, which has a MPCa value of 2×10^{-11} μc/cc., a value of 15 times less than that for iodine-131. The uncontrolled release of the non-volatile fission products must be carefully prevented as they constitute the major portion of the total activity produced in nuclear reactors.

(3) Particulate Dispersed Fuel Materials are fissionable isotopes of uranium and plutonium. When these heavy metals disintegrate, they give off high energy, strongly ionizing alpha particles and the effects of which, within the body, are more damaging than those from gamma rays and beta particles. Like radium, these metals seek out bone tissue where their damagnig effects are accumulated over a long period of time. The low MPCa values (2×10^{-13} μc/cc. for plutonium-239) make difficult the problem of air monitoring, due to the presence of alpha emitters from natural radon and thoron compounds which in themselves are of little consequence.

(4) Induced Activity arises when air is used for cooling reactors as the dust and impurities it carries may become activated in the high neutron flux. For this reason, cooling air must be filtered. Even so, various gaseous components of air may become activated by exposure to a neutron flux. The concentration of nitrogen-16, argon-41, oxygen-19, and neon-23 produced, vary with the power level of the reactor and with the flow rate of the coolant air. Few reactors in this country, except for several small experimental reactors, are air cooled; however, ventilating air may be caused to circulate inside the shielding of some types of reactors, thereby also becoming activated. The maximum permissible concentrations for a few of the more frequently encountered radioactive isotopes in air are listed in Table I. These concentrations apply for continuous exposure in unrestricted areas.

Reactor Types

Utilization of atomic energy for peaceful purposes, although in its infancy, is advancing at a fast pace. In this country, the nuclear reactor business has tripled in 1956, with industry building or contracting for 59 new reactors (29 power reactors, 30 research and test reactors). Industrial spending on all phases of atomic energy will total approximately $500 million this year and about $270 million will be spent for civilian and military power reactors alone in 1958.[4]

The primary purpose of the intense program under way for power reactors is the demonstration of technical and economic feasibility of some reactor types. As a part of this program, the first commercial-scale civilian power reactor in this country, the Pressurized Water Reactor (PWR), capable of producing 65000 kw. of electricity, will be placed in operation the latter part of this year at Shippingport, Pennsylvania. Out of the development program have emerged many different types of reactors: pressurized water, boiling water, homogeneous, sodium graphite, liquid metal fuel, fused salt, fast breeder, organic moderated, *etc.*

However, nuclear reactors are more generally classified as 2 types according to the manner in which the fuel and moderator are distributed: homogeneous or heterogeneous. Mod-

TABLE I
Tolerance Concentrations for Radioisotopes in Air

Radioisotope	Maximum Permissible Concentrations	
	Microcuries/cc. of air	Atomic ratio, atoms/atom air
C^{14}	5×10^{-8}	1.1×10^{-10}
Na^{24}	1.6×10^{-7}	1.1×10^{-9}
P^{32}	1.4×10^{-8}	2.2×10^{-11}
A^{41}	5×10^{-8}	4.3×10^{-10}
I^{131}	3×10^{-10}	2.6×10^{-12}
$Sr^{90} + Y^{90}$	2×10^{-11}	2.2×10^{-11}
Xe^{133}	4×10^{-7}	2.3×10^{-10}
U	1.7×10^{-12}	3.0×10^{-10}
Ra	8×10^{-13}	5.0×10^{-11}
Pu	2×10^{-12}	2.1×10^{-10}

erators, usually graphite or water, are employed in all reactors, except fast reactors, to curb the speed of the neutrons and so create extra fission reactions.

In homogeneous reactors, the fuel is distributed throughout the fluid either as a soluble metal or salt, or as finely dispersed solid particles called slurries. The fluid may be heavy or light water, a molten metal or a fused salt. In this type of reactor, the fuel is pumped through heat exchangers and transfers the heat generated in the reactor core to a secondary steam system. One main advantage of the homogeneous type reactor is that the fission product content can be maintained at a low level by continuously withdrawing a side stream from the reactor and separating the fission products from it, all operations being carried out with the fuel in easily-handled solution or slurry form. Fuel to replace that burned up can be added continuously to the reconstituted fuel as it is returned to the reactor system.

In this type of reactor, the volatile fission products are liberated directly from the fuel almost as soon as they are formed. Homogeneous power reactors, which have been designed, include the aqueous systems such as the Homogeneous Reactor Test (HRT) at Oak Ridge National Laboratory, and the Pennsylvania Advanced Reactor (PAR) sponsored by Pennsylvania Power and Light Company, and the fused bismuth metal systems, such as the Liquid Metal Fueled Reactor, proposed by Brookhaven National Laboratory, provide for several months hold-up of the gases on activated charcoal adsorbers in the off-gas facilities. After this hold-up period, only the krypton-85 isotope remains in any appreciable quantity in the off-gas stream, which is diluted with large amounts of air before being sent up the stack.

In heterogeneous reactors, the fuels in some convenient form, such as metal plates or rods with protective coatings, cans or tubes, are spaced in a lattice arrangement throughout a volume of moderator. An example of this type employs an arrangement of plates consisting of uranium-zirconium alloy in a zirconium cladding. The unit is submerged in a light water which acts as moderator and also provides cooling when circulated through a heat exchanger.

The solid metal fuel must be protected from oxidation and corrosion by a jacket that *(1)* is a good heat conductor, *(2)* has good structural properties at high temperatures, *(3)* has low neutron absorption, and *(4)* has high corrosion resistance. A metal fulfilling these requirements quite well is zirconium. Since the radioactive fission products are formed within the canned metal, no large amount of fission product activity can be released unless there are imperfections in the jacket. These may occur during fabrication of the fuel element or by rupture of the jacket during handling and operation.

There are 2 sources of airborne contamination connected with the operation of solid fuel power reactors. The first source as previously mentioned is an imperfection or failure of the jacket which protects the metal fuel elements. Even a pin-hole leak in a jacket will permit release of the

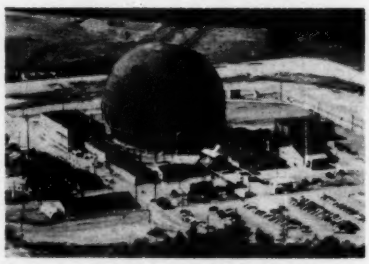

Fig. 1. Spherical containment vessel at Knolls Atomic Power Laboratory, operated by General Electric Company.

fission products to the coolant stream. The uranium will readily oxidize at high temperature, and particles of uranium oxide which contain fission products will be carried out by the coolant. The Oak Ridge graphite-uranium reactor, which has a single-pass air cooling system, has an elaborate filter installation to prevent particles larger than submicron size from escaping in case of an accidental slug rupture.

The second source of air contamination in normal reactor operation is induced activity of the coolant. The coolant may be used in a single-pass system or circulated in a closed loop. The amount of activity formed in the coolant may be determined for each element. It depends on the neutron flux, the absorption cross-section for the element, the concentration of the element in the coolant, and the half-life of the isotope formed.

Almost all of the activity produced in air passing through a reactor is from argon which normally comprises about 0.93 weight % of the air. Permissible concentrations of radioactivity may be achieved by diluting the coolant and placing the point of discharge in a favorable location. At the Brookhaven National Laboratory, the effluent stack servicing the air cooled reactor is over 300 ft. tall. The volume of air flow for cooling the reactor is about 300,000 ft.^{3}/min. The air is filtered before it enters the reactor by American Air Filter FG-100 deep-pocket filters and again before it leaves the reactor building by Dollinger Glasstex deep-pocket filters.

If the intake air is not filtered, or if in flow through ducts to the reactor the air picks up dusts of various kinds, the dusts become irradiated in the reactor and contaminate the cooling air streams with radioactive particulates. Usually the incoming air is filtered, and provision is made to prevent dust in air passageways and ducts.

If water is the coolant, the dissolved impurities are often a source of great activity, and consequently the water is usually highly purified and demineralized by ion exchange, *etc.* In normal reactor operation, however, the cooling water is not a source of airborne activity.

All reactor plants being designed and built in this country for the production of electrical power have coolants circulated in a closed loop. Most of them use gas-tight containment vessels to ensure that there will be little possibility of release of radioactive gases and particulate material to the atmosphere in the event of a major failure of any part of the reactor or coolant circuit. A containment vessel is an outer structure which encloses the entire primary reactor vessel and all or portions of the primary coolant circuit. Such vessels must be designed to withstand without leakage the most disastrous incident assumable under operating conditions. These are called the *maximum credible accident.* Fig. 1 shows the spherical containment vessel at Knolls Atomic Power Laboratory, operated by the General Electric Company. This vessel houses the reactor and auxiliary power generating equipment which is the prototype for the Navy's Seawolf submarine.

In Fig. 2 is seen a front view of the Experimental Boiling Water Reactor Building at Argonne National Laboratory near Chicago. The transformer substation is at the rear. This reactor was completed late last year

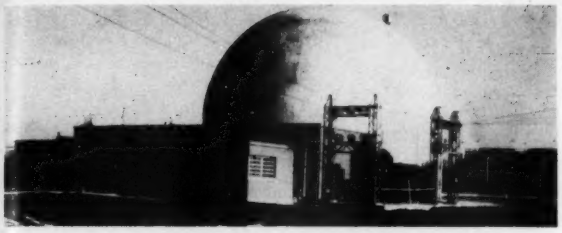

Fig. 2. (above) Front view of the Experimental Boiling Water Reactor at Argonne National Laboratory.

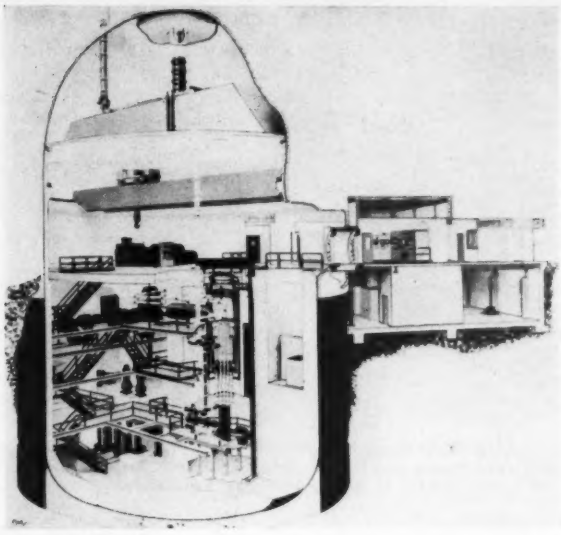

Fig. 3. (right) Experimental Boiling Water Reactor at Argonne National Laboratory. Perspective of entire plant.

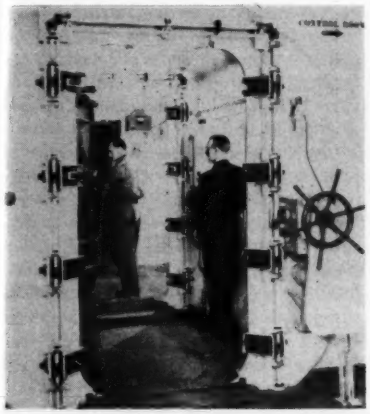

Fig. 4. One of the air-lock doors in the gas-tight power plant building, Experimental Boiling Water Reactor at Argonne National Laboratory.

and is now operating since February 9, 1957, at its full design power level of 5000 electrical kw. A perspective view of the entire plant is shown in Fig. 3. The reactor and all auxiliary equipment are located in the airtight containment vessel. The operating area is completely outside the containment vessel. Entry into the gas-tight power plant building can be made only by going through air-lock doors, one of which is shown in Fig. 4. During normal operation, one of the doors is in a closed position. Fig. 5 shows a sectional view of the power plant building. The main floor plan of the power plant building is seen in Fig. 6 and in Fig. 7 is seen the multiple steel beam on top of the reactor which guarantees against an upward explosion of the reactor. Fuel handling equipment is shown in background. A general view of the lower half of the containment during construction is shown in Fig. 8. The vessel is 80 ft. in diam. and 119 ft. high. The cylindrical portion is constructed of $\frac{5}{8}$ in. steel and the dome of $\frac{3}{8}$ in. steel. Approximately $\frac{2}{3}$ of the building is constructed below grade. The vessel can withstand 15 psig. internal pressure, with leakage of less than 100 ft.^{3}/24 hr.

Supporting Facilities

Chemical Reprocessing Plants

In a chemical reprocessing plant, solid fuel elements are dissolved and processed to separate the unfissioned uranium from the fission products. The gaseous radioactivity liberated when spent metallic fuel is dissolved consists principally of the noble gases xenon-133 and krypton-85 and the halogens iodine-131 and bromine-82. Of these elements, the one of primary concern is again iodine-131.

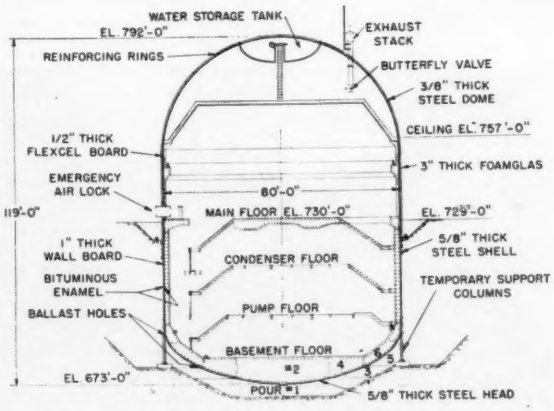

Fig. 5. Sectional view of Power Plant Building of the Experimental Boiling Water Reactor at Argonne National Laboratory.

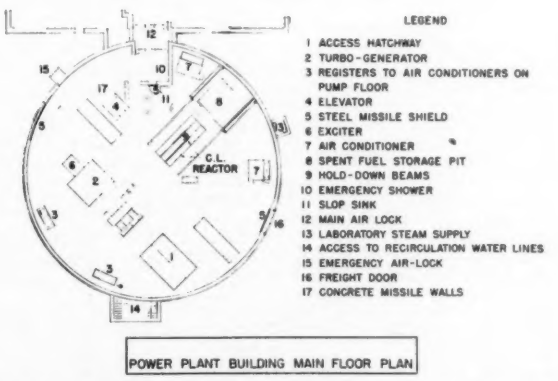

Fig. 6. Power Plant Building Main Floor Plan of the Experimental Boiling Water Reactor at Argonne National Laboratory.

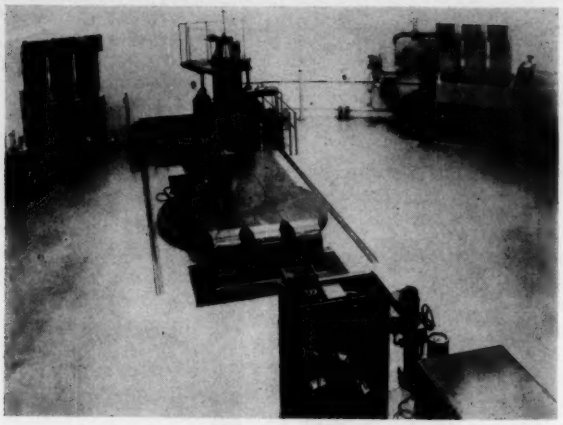

Fig. 7. View of Power Plant Building Main Floor showing multiple hold-down beams and fuel-handling equipment. Experimental Boiling Water Reactor at Argonne National Laboratory.

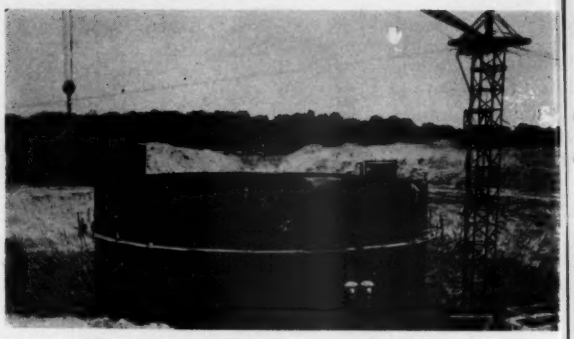

Fig. 8. General view of the lower half of the Containment Vessel during the construction of the Experimental Boiling Water Reactor at Argonne National Laboratory.

For removal of gases such as iodine-131, scrubbing with spray or baffle plate scrubbers, utilizing caustic absorbents only, yields efficiencies of 60 to 80%. Use of silver reactions has been applied successfully for trapping out iodine. A silver reductor unit composed of a tower packed with beryl saddles coated with silver nitrate and maintained at an elevated temperature gives removal efficiencies of iodine greater than 99.99%. Most of the units installed remain in operation for periods beyond 2 years before replacement or regeneration is required.

The radioactivity in the off-gases depends upon the age of the irradiated fuel, counted from the time the fuel was removed from the reactor. It is common practice to allow a reasonable *cooling* period of about 120 days for radioactive decay before dissolving and thereby reducing the activity of the off-gases by a factor of 10000 or more. Aging is used in particular to reduce the iodine hazard.

In fuel reprocessing plants, the actual operations are carried out in sealed compartments or *cells* by remote control and behind much shielding to reduce the intense radiation from the process. Most equipment is installed in duplicate to prevent clogging or leaking pipelines or valves from hindering the operation. Off-gas systems are provided in cells which will handle the gases and mists evolved in any of the process vessels. Studies made on the stack effluent of such systems have shown that almost all of the effluent is either gaseous or of a particulate nature less than 1 μ in diam. Before being sent up into tall stacks for dispersal into the atmosphere, the effluent gases are cleaned of particulate matter by various high-efficiency units including electrostatic precipitators, wet collectors, CWS-type filters, sand and glass fiber filters. Replaceable filter units must be designed for easy replacement. Owing to their usually highly contaminated condition after use, very careful methods must be employed when changing these exhaust filters, after which they are generally permanently buried.

Supplementing the system for off-gas treatment, a separate system for the ventilation air of the cells is usually installed. This air is also scrubbed or filtered before it goes up the stack in the event that a leak or failure of process equipment releases activity into the cell. Fig. 9 shows a schematic design of the waste gas collection system at ORNL. Off-gases from dissolver and process vents first pass through the Cottrell Electrostatic precipitator and American Air filters before being discharged up the 250 ft. stack. Ventilation air is filtered by American Air and CWS-type filters, if necessary, before being discharged. The base of the 250 ft. stack and Cottrell precipitator are shown in Fig. 10. A close-up of the Cottrell precipitator is shown in Fig. 11. The wall of concrete blocks which partly surrounds the precipitator serves as a gamma shield for personnel protection.

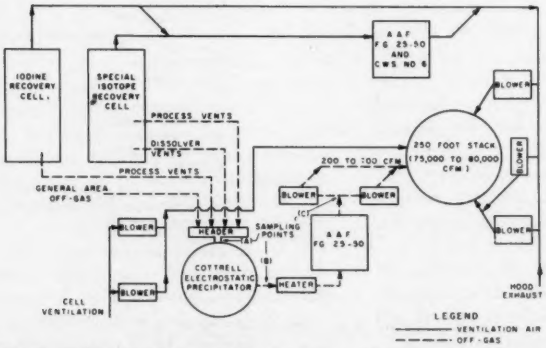

Fig. 9. Schematic design of the waste gas collection system at Oak Ridge National Laboratory.

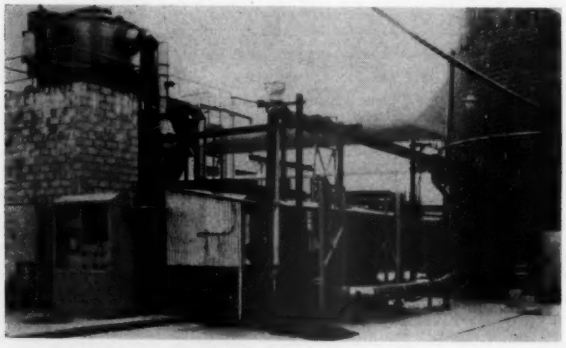

Fig. 10. Base of 250 ft. stack and Cottrell precipitator at Oak Ridge National Laboratory.

Waste Disposal Facilities

Radioactive wastes which are liquid or solid require separate disposal facilities in addition to those already mentioned. These facilities include treatment plants for chemical residues, incinerators, sewage plants which handle radioactive liquid wastes, and burial and storage areas for solid wastes.

There are 2 philosophies which are applied to the disposal of radioactive wastes. These are (a) *concentrate and contain* and (b) *dilute and disperse.*

Examples of the first policy are (1) the evaporation or segregation of liquid wastes followed by piping into tanks or underground cribs and (2) the burial of contaminated solids or drums of liquid. Certain high-level wastes may be contained in concrete mixes before burial. Adequate coverage is provided to shield against radiation at the surface.

At particular sites off the Atlantic and Pacific coasts, radioactive solid wastes are disposed of at sea by dumping in designated areas in water off the continental shelf. It is the general practice to encase these wastes in a mixture of concrete, usually within steel drums.

As an example of the second policy, the closely regulated discharge of liquid waste to rivers and streams is cited. Large retention basins are used to permit radioactive decay before liquids are finally released. Of course, the discharge of gaseous wastes through stacks and vents is another example of the *dilute and disperse* principle.

An operation which will most likely be carried out in chemical reprocessing plants, in addition to recovery of fissionable material, is the separation of special radioactive isotopes of high activity for use as radiation sources. Such a separation operation may produce gaseous effluents similar to those found in the reprocessing plant itself.

Measurement and Monitoring of Airborne Activity

Radioactivity cannot be detected by human senses or by ordinary analytical techniques applied to other industrial wastes; however, with proper instrumentation, it can readily be measured at significant levels. Also, it is virtually impossible, as well as uneconomical, to treat any given amount of an element so that its radioactivity is reduced. Time is the only significant factor that will reduce radioactivity.

To measure the gross activity of radioactive gases, continuous monitors are in common use today in nuclear plants. The monitor usually consists of a gas chamber with detector, pumping system, flow-rate meter, and recorder. The radioactive gas to be monitored is passed through a filter to eliminate contamination of the gas chamber by airborne radioactive particulates. Depending upon the application and the type of radiation emitted, the gas chamber houses either a

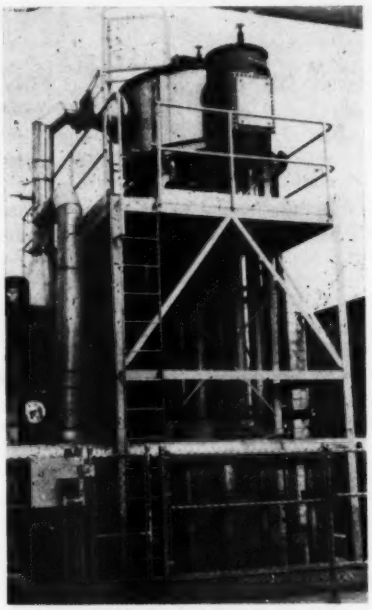

Fig. 11. Close-up of Cottrell precipitator at Oak Ridge National Laboratory.

scintillation, proportional, or a Geiger-Mueller detector. The gas chamber is surrounded by a thick lead shield to eliminate background radiation interference. A vacuum pump usually provides for a flow of 5 to 10 ft.^{3} of air/min. through the gas chamber. In some cases, it may be desirable to differentiate between various types of gas activities, and this can be accomplished by use of a pulse height analyzer.

In most installations it is desirable to monitor particulate matter, as well as gaseous activity. Devices employed for monitoring particulate radioactivity in the atmosphere employ filters of 2 general types: the fixed filter and the continuous moving filter. The fixed filter is constructed so that air is drawn through a filter at a known rate for a measured period of time. The exposed filter is then removed from the sampler and monitored for radioactivity. The fixed filter has the disadvantage of not furnishing a continuous record of the instantaneous amount of radioactivity in the sampled air.

The continuous moving filter system records the level of radioactivity collected on a moving tape of filter paper. The rate at which the sample is drawn through the filter paper and the speed of the moving filter, when combined with the counting rate of a scintillation, proportional, or Geiger-Mueller detector, permit calculation of radioactivity in the atmosphere on a continuous basis.

Each nuclear plant should have a Health-Physics Department which is responsible for the protection of personnel from the harmful effects of radioactivity. Its activities would include routine procedures of radiation protection, area and personnel monitoring, the recommendation of appropriate protective clothing and laundering, safe equipment and procedures, the determination of acceptable standards of operation, and the solution of problems incident to the effective and practical protection of all personnel from harmful effects of radiation. In addition, the Health-Physics Department would be responsible for the maintenance of safe levels of radioactivity in neighboring areas and environment for the protection of the general public.

Acknowledgment

The writers wish to express their sincere appreciation to the Argonne National Laboratory, the Oak Ridge National Laboratory, and General Electric Company for sending the photographs and allowing us to present them in this paper.

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Method for Tracing the Ground-Level Distribution Of Stack Gas Emissions*

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The complexity of the air pollution problem of a large community is well illustrated by the confusion of opinions that usually prevail as to the relative contribution of various potential sources, industrial, domestic and others. There is an all too common tendency to draw conclusions in a superficial manner based on evidence of visual appearance of stack emissions or similar tenuous evidence. Any scientific tool, therefore, that will enable one to distinguish the gas-borne effluents of a particular stack emission and to estimate quantitatively its proportionate share of the total resulting intensity of air pollution will be regarded as valuable in its ability to minimize the need for speculation.

In some instances the stack gases of an industrial process may contain a substance which, because it does not occur normally in the atmosphere in significant amounts, may itself serve usefully as a tracer substance. Then a measurement of the concentration of that substance at various significant ground-level locations, in conjunction with data on its rate of discharge into the atmosphere, provides a basis for calculating the rate of dilution of these stack gases at each location and in various weather conditions. The resulting dilution rate figure could then be applied to calculate the concentration at ground level of some particular pollutant contained in the same stack gas emission.

A more universally applicable technique is one in which a tracer substance is introduced in measured quantities to the stack gases to be studied and its identity sought in air samples obtained at ground level.

One method that has been usefully applied[1, 2, 3, 4] involves the release of finely divided particles of fluorescent powder into the gas or air stream to be studied. The fluorescing characteristic of the collected particles when illuminated by ultraviolet light enables them to be identified under the microscope.

In the present development we sought a method that would overcome the disadvantages of that technique, the principle one of which is the very large expenditure of manpower required for its implementation especially in the operation of field sampling equipment. The effort required in the present technique is quite modest in its time requirements; it is possible for 2 men to handle all the details in a survey of considerable magnitude. The cost of its application is correspondingly low.

Procedural Principles

Economy of manpower in the ground-level sampling at numerous locations dictated the need for completely automatic apparatus. It would also be desirable that each item of sampling apparatus be relatively inexpensive and quiet in operation. These specifications were met by the automatic smoke sampler which had been developed by us to meet these very specifications several years ago and we accordingly directed our efforts to the problem of selecting a tracer substance which would be effectively collected by the filter paper of our sampler. Other specifications for such a tracer required it to be nontoxic and not perceptible to persons in the concentrations that would prevail at ground level; that it not be a normal constituent of the atmosphere; and that it provide a stable dispersion in the atmosphere. The last-named specification would be ideally met by the use of a gas or vapor and in fact we were successful in the development of a system involving the use of mercury vapor which was quantitatively absorbed by filter paper that had previously been treated with an impregnant[5]. This development, however, was quickly superseded by the more sensitive method that is the subject of this paper.

It is well known that radioactive substances can be measured in very minute quantities, and isotopes have accordingly played an important role in various fields of technologic investigation. Such substances could serve usefully to tag stack gases if it were not for the obvious objections to their use.

The present technique involves a procedure in which a non-radioactive tracer substance having special properties is dispersed in the gas stream to be studied. After the tests are completed the field samples are made radioactive by irradiation in an atomic pile and the quantity of tracer substance present determined by measurements of induced radioactivity. Thus the sensitivity of the radioactive measurement is enjoyed without the hazards and inconvenience. This is the technique of neutron activation now well known to radiochemists.

Test Procedure

Antimony oxide powder was selected as the tracer substance partly because it is not normally present in the atmosphere in significant concentrations and partly because it has a high neutron activation cross-section and its radioisotopes, principally antimony-122, have energetic radiation easy to detect.*

An antimony oxide powder disperser is required to inject the tracer ei-

* Presented at the 50th Annual Meeting of the Air Pollution Control Association held at St. Louis, Mo., June 2-6, 1957.

* American Petroleum Institute, Smoke and Fumes Committee, Memorandum "Neutron Activation Analysis for Gas Tracing," B. A. Fries, July 28, 1953.

Fig. 1. The AISI Automatic Smoke Sampler.

er into the stack gas stream to be udied or into the atmosphere at me significant source. The ground-vel samplers in suitable numbers e located at selected points in the egion being investigated and can be laced in operation well in advance f the time selected for an actual run. he samplers incorporate a simple ming mechanism which automati-ally advances the strip of filter paper rom the supply roll at pre-determined ntervals, usually 1 or 2 hr. This fea-ure together with its noiseless oper-ting characteristics, makes it par-icularly convenient in that they can e allowed to operate, if necessary, for many days in advance of the actual est period while one is waiting for the development of suitable wind or other weather conditions. When these conditions develop, the operator starts the tracer powder dispersing equipment. From then on, the dura-tion of the test is usually depend-ent on the character of developing weather.

The stream of tracer powder is con-tinuous. Action of the samplers whereby a sequence of 1- or 2-hr.-long samples are taken automatically at each location means that one conducts a series of runs spanning the total time period of the test without atten-tion from anyone.

At the end of the test period, the samples on the filter paper strips are collected at any convenient subse-quent time, usually the following day.

The collected samples are brought back to the laboratory, labeled, pack-aged and sent to the agency selected for the irradiation. We use the fa-cilities of the Oak Ridge National Laboratory.

The one-week period of irradiation in the pile involves an elapsed time of somewhat less than 2 weeks. On their return, they are processed for sepa-

Fig. 2. Group of samplers ready for disposition in the field.

ration of soot and other extraneous pollutants that have been deposited on the filter paper along with the tracer, and the radioactivity of the concentrated antimony oxide deter-mined by means of a Geiger counter. By reference to the activity of the known quantities of antimony which are included as standards in the ir-radiation procedure, the amount of antimony present is determined.

The sensitivity of the method per-mits the measurement of less than 0.01 μg. (0.00001 mg.) with an accu-racy of 0.003 μg.

Air Sampling Apparatus

The field sampling instrument for collection of tracer particles at vari-ous locations, the AISI Automatic Smoke Sampler[6] shown in Fig. 1 and 2, operates on 110 volts. It consists of a diaphragm pump which draws the air sample through Whatman No. 4 roll filter paper at the rate of 0.25 cfm. The air sample is aspi-rated continuously throughout a 1- or 2-hr. period when the strip of filter paper is automatically shifted and sampling resumed at a new position on the paper.

Powder Disperser

The dispersing equipment consists of an ejector connected to a com-pressed air line delivering 50 to 60 cfm. free air. The tracer powder flows from a hopper onto a rotating plate from which it is picked up by the ejector and discharged into the selected gas stream. A compressed

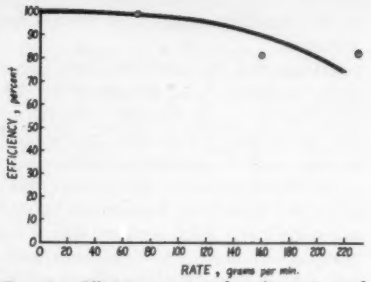

Fig. 3. Efficiency curve for dispersion of antimony oxide powder.

air vibrator is employed to insure uni-form flow from the hopper.

We were cognizant of the hazards to success if the powder were ineffec-tively dispersed by the compressed air ejector since it is notoriously difficult to break down the flocculent aggre-gates in some powders. In the pres-ent instance, the degree of dispersion was determined by passing a fraction of the dispersed aerosol through a specially designed sedimentation chan-nel[7]. The proportion settling out in this channel is an indication of the effective particle size and *efficiency of dispersion* is described in terms of the percentage by weight having an effective *Stokes Law-particle size* smaller than 5 μ. For dispersing rates up to 100 g./min., the *efficiency of dispersion* is 90% or better. At 160 g./min., the efficiency is reduced to approximately 80% (see Fig. 3).

Field Test Procedure

If the tracer powder is dispersed into a stack gas stream, the actual rate of emission from the stack should be measured since conditions in some gas streams may cause ag-glomeration and accelerated sedimen-tation of the tracer particles.

The field samplers may be placed in garages, barns, cellars, crawl spaces, sheds, or porches near the de-sired locations. Although the sam-pler operates quietly, it may be nec-essary in some locations to provide an auxiliary sound-proof enclosure. Rubber tubing, ½ in. O.D. or larger, leading from the sampler to the ex-terior of the shelter should be kept as short as possible. The samplers are set so they will sample simultane-ously and continuously for successive periods of time. We usually adjust the timer for 2-hr. periods.

When weather conditions are suit-able for the test objectives the pow-der dispersion equipment is set in op-eration. Since the samplers operate automatically there is no time limit as to the length of a field test as long

as the weather conditions remain favorable.

At the end of a test, the filter paper tapes from the field samplers are collected and returned to the laboratory for processing. Extreme care should be exercised to prevent contamination of the field samples; the person operating the dispersing equipment should not collect the field samples without a complete change of clothing and bathing. An automobile contaminated in any way with the tracer should not be used in collecting the field samples.

Analysis of Samples

Preparation of the samples for analysis involves cutting the individual spots from the filter tape, labeling each with a metal stamp, and packaging in a quartz tube for subsequent irradiation.

The irradiated samples are returned in about 10 days and are then processed for concentration of the antimony. Each sample is leached for 2 hr. in 5 NHCl. The supernatant solution containing dissolved antimony, if any, is decanted and carrier antimony added to enhance the recovery efficiency of any radioactive antimony present. Chromous chloride solution is added to this solution to reduce and precipitate the total antimony in the form of the free metal.

The suspension is then passed through a 1 in. diam. filter, washed with water and then with a small quantity of acetone to accelerate drying of the wet precipitate and paper. The filter paper contains the concentrated radioactive antimony and is ready to count.

Counting

The precipitated antimony is counted with a shielded end window Geiger tube whose window thickness is 30 mg./cm.^{2} A window of this thickness will absorb most of the very soft beta radiation that is found as a contaminant; the high energy beta particles from the radioantimony will pass through the window with very little attenuation. During counting, the sample should be as close to the counter window as possible in order to gain the advantage of good counting geometry.

Fig. 4. Stack into which tracer powder was injected. Height of stack is 400 ft.

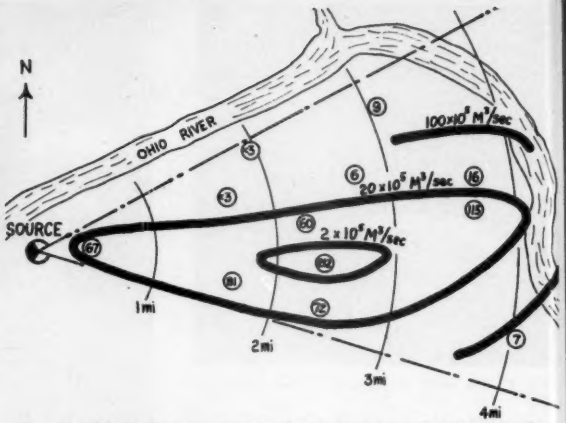

Fig. 5. Map showing geographical location of field samplers. The heavy lines are contours of equal concentration.

If there were no contaminant in the sample, it would be best to count the antimony as soon as possible after the termination of the neutron irradiation. However, a short-lived high-energy contaminant in the antimony precipitate that is thought to be As^{76} persists in spite of efforts to eliminate it. After a 3-day waiting period, the arsenic activity has decayed to a level which in relation to decay of the antimony tracer, represents minimum background interference due to this contaminant.

Example Application

Results of 1 test are presented in the following. The stack whose dispersion characteristics were selected for study is illustrated in Fig. 4. Twelve samples were disposed in a 45° easterly sector up to a distance of 4 miles from the stack. Three consecutive 2-hr. runs were included in this particular test, results of which are given in Table I.

The background, or blank, is obtained by analysis of a number of samples spanning several hours preceding the start of the test. The various activity values obtained from these pre-test samples are handled by conventional statistical procedures to arrive at a value background counting rate for subtraction from the gross counting rate on samples obtained during the test period.

The accuracy of the analysis is arbitrarily defined as the weight of antimony equivalent to the standard deviation of the pre-test background samples.

In Fig. 5 the test area is shown together with the concentrations of the tracer at various locations during the 6-8 pm. run. There are really an insufficient number of test locations to establish with complete validity the contour lines of equal concentration also shown in the diagram. It nevertheless illustrates how contours can be employed to depict the results of such tests.

Application of Results

With these results before us and data on antimony tracer dispersion rate at the stack (10^8 mμg./sec.) one can transform the ground-level concentration data into units which describe the extent to which the tracer (and any other of the constituents of the stack gas) have been diluted during travel of the gas stream to any of the test locations. The equal concentration contours have been so labeled.

Suppose the case where the stack gases were emitting sulfur dioxide, fluoride or any other gas at a rate of 100 lb./hr. Calculate the concentration for which it is responsible at the ground level location where the dilution rate was established to be 20 x 10^5 m.^{3}/sec. By direct arithmetic it is calculated to be 0.0022 ppm.

If the concentration at the same location had been measured directly

TABLE I

Concentrations of Antimony Tracer Found at 12 Sampling Locations During 3 Runs of Field Test No. 11.

Antimony Dispersal Rate = 0.1 gm./sec. = 10^8 mμg./sec.

Period Test 3/2/56	Concentration of antimony at each location, mμg/m.^{3}											
	1	2	3	4	5	6	7	8	9	10	11	12
2-4 pm.	46	—	7	—	19	45	20	77	—	—	9	7
4-6 pm.	112	54	13	—	20	174	81	45	—	—	67	26
6-8 pm.	67	81	—	—	72	212	60	6	9	7	115	16

during the same time period, one could state the percentage of the total contaminant due to the stack emission.

Summary

A new method has been described whereby the stream of gases from a particular stack can be tagged by addition of small quantities of antimony oxide powder as a tracer substance. Automatic air samplers operating simultaneously in the surrounding territory will pick up the tracer in inverse proportion to the dilution experienced by the stack gases. Quantitative recognition of the tracer powder in amounts as small as 0.01 μg. is effected by a simple laboratory procedure involving neutron activation analysis.

Acknowledgment

This technique was developed by the authors at the request of the Smoke and Fumes Committee of the American Petroleum Institute whose financial support made it possible. The studies were conducted at Mellon Institute in 1954-1956 where two of the authors formerly served as fellows, and also research engineers on the staff of Industrial Hygiene Foundation.

Special acknowledgment is due the advisory committee whose technical advice was invaluable in the course of this research: Dr. Bernard A. Fries, Chairman, Mr. Ralph O. Clark, Mr. Frank W. Melpolder, and Mr. Frederick G. Roop; and to Mr. W. H. Claussen, then Executive Secretary of the Smoke and Fumes Committee.

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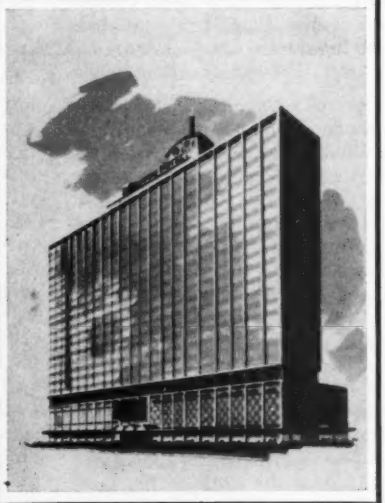

The Fulham-Simon-Carves Process for the Recovery of Sulphur from Flue Gases*

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People have for many years insisted that the water which they drink should have a high standard of purity and it is surprising that only comparatively recently has attention been focused on the purity of the air which they breathe.

Admittedly as long ago as 1661 John Evelyn wrote a treatise[1] entitled *Fumifugium* in which he dwelt at length on the evils of polluting the *Aer of London* and suggested measures to prevent this nuisance. He submitted his dissertation in the hope that King Charles II and his Parliament would pass an act to abate smoke, but nearly 300 years were to elapse before general legislation was introduced.

Recently, under pressure of public opinion and guided by the findings of the Beaver Committee Report on Air Pollution[2], the British Parliament has passed the Clean Air Act of 1956. Local legislation has, however, been adopted from time to time in Britain, America and other countries where restrictions have been placed on smoke emission, and in a number of towns *smokeless zones* and *smoke control areas* have been introduced.

The serious economic consequences of atmospheric pollution have recently been impressed upon the British citizen by such estimates as have been made in the Beaver Committee Report. The cost to Great Britain has been estimated at £250,000,000/year in direct costs and loss of efficiency. Direct costs include laundry and domestic cleaning; cleaning paintwork and repair of buildings; corrosion of metals and damage to goods. The effect of air pollution on the health of the worker and the interference of heavy *smog* with transport are listed as the 2 chief causes of the loss of efficiency. When in addition the loss due to the imperfect combustion of coal is taken into account, the total sum approaches £300,000,000/year. Air pollution is, therefore, becoming a subject of outstanding importance to Great Britain and much research and development work is being carried out to combat it.

Pollution of the air arises generally from the combustion of fuels such as coal and oil, the main pollutants discharged being smoke, grit and dust, and sulphur oxides.

Industrial smoke can be reduced to a bare minimum by a properly designed and operated combustion plant, and the increasing use of electric or diesel locomotives in shunting yards should eliminate a large proportion of railway smoke. The reduction of domestic smoke is not so simple and depends upon the availability of smokeless fuels and burning appliances. Improvement here can only be achieved over a considerable period of time.

The prevention of the grit and dust nuisance is largely a matter of spending sufficient money to install arresting equipment. This expenditure is unfortunately not usually easy to justify as it does not add to the efficiency of the process concerned. Its value must be measured in terms of preserving the local amenities, although in some cases it is a condition which must be fulfilled before permission is given by the local authority to operate a plant.

Sulphur oxides, the most deleterious products of the combustion of fuels, are probably the most difficult to eliminate. Sulphur is present in coal in 2 main forms, organic sulphur intimately associated with the coal structure and pyritic sulphur which occurs in different stages of sub-division in the coal. Organic sulphur cannot be removed by cleaning the coal physically or mechanically, and in many cases pyrites is so finely disseminated throughout the coal that separation is not possible. This means that the sulphur in coal can only be reduced to a limited extent by conventional coal cleaning methods and so far no other processes have been developed.

In the combustion of oil practically the whole of the sulphur content is discharged in the waste gases. In the case of coal and coke in domestic appliances, about 80% of the sulphur is discharged in the chimney gases. When burnt in industrial furnaces, where the temperature is higher, about 90% of the sulphur appears in the waste gases. This sulphur is present mainly as sulphur dioxide and partly as sulphur trioxide. The proportion of sulphur as the trioxide is usually not more than 5% that of dioxide.

An estimate for Great Britain shows that an amount of sulphur equivalent to more than 5,000,000 tons of sulphur dioxide or to about 8,000,000 tons of sulphuric acid is discharged into the atmosphere annually. When one considers that Great Britain uses about three-quarters of a million tons a year of sulphur and that three-quarters of this is imported, either as sulphur or sulphides, it becomes evident from economical considerations alone how desirable the recovery of at least part of the sulphur discharged to the atmosphere would be. It would enable sulphur to be obtained from indigenous sources, an important point particularly in view of the temporary shortages of sulphur with which the world appears to be threatened from time to time.

An examination of the different ways in which coal is consumed shows that about 17% of the sulphur discharged is from domestic appliances, about 22% from electricity works and 35% from industrial installations. The removal of sulphur in the case of small users of fuel, in particular the domestic user, appears at present to be impracticable. It is however, possible to remove the sulphur from the waste gases of large installations such as industrial steam raising plant and power station boilers. In fact the only processes that have been operated for long periods have been used at the electricity generating stations

* Presented at the 50th Annual Meeting of the Air Pollution Control Association held at St. Louis, Mo., June 2-6, 1957.

of Battersea, Fulham and Bankside in London. Removal of sulphur from such waste gases does not appear to have been practised elsewhere.

Flue Gas Washing Processes Used On A Full Scale in Great Britain

It is of interest to mention here how the initial impetus was first given to the construction in Great Britain of full scale flue gas washing plants for the removal of sulphur oxides from boiler flue gases.

In consenting in 1927 to the construction of the first third of Battersea Power Station, the Electricity Commissioners imposed a condition that the London Power Company should take the best known precautions for the due consumption of smoke and for preventing as far as reasonably practicable the evolution of oxides of sulphur[3]. In 1929, while this power station was still under construction public opinion was aroused by a law case brought against Manchester Corporation by a farmer who claimed that his crops were being damaged by flue gases discharged from Barton Power Station. This case, which was eventually referred to the House of Lords before being settled, was won by the farmer. As a result, a considerable amount of comment was made in the press, particularly in relation to the erection of large power stations in the centre of London. The London Power Company, therefore, decided that in addition to using coal with a low sulphur content, some method of removing sulphur oxides from flue gases must be devised in order to ensure official consent for the completion of the station.

Later, in 1930, the Electricity Commissioners held a public enquiry before consenting to the erection at Fulham of a further power station of approximately the same capacity as Battersea and within 2 miles of it. The Commissioners, after considering the results of this enquiry, imposed a limit of 0.03 gr. of sulphur/ft.^{3} of chimney gases as a condition to be met in operating this power station.

Arising from these restrictions the Battersea Effluent Process was developed, and later the Howden I.C.I. Cyclic Lime Process. These 2 processes will now be briefly described.

Battersea Effluent Process

This process was developed by the London Power Company and operated for several years before World War II. At the beginning of the war it was shut down to prevent the white plumes from the chimneys being used as a guide by enemy aircraft.

After the war modifications were made to the scrubbing system and this modified process is still in use. More recently the same process has been installed in a new oil-fired power station at Bankside, also situated in the centre of London and on the river Thames.

Basically the process consists in scrubbing the flue gases with large volumes of Thames water. The Thames water supplies most of the alkalinity needed to neutralize the sulphur oxides removed from the flue gases but some additional alkali is required in the form of a chalk slurry which is added to the water fed to the top of the scrubber. This scrubbing medium then flows down through the scrubber in counter-current flow to the flue gases, which pass upwards through it. Manganese sulphate is added to the scrubbing liquor as it comes from the base of the scrubber to assist in the oxidation of the liquor. After passing through a settling tank, which removes small quantities of fine solids which have passed into the scrubber with the flue gases, the liquor is aerated in an oxidising tank to ensure that the de-oxygenating material is reduced to a minimum before discharge to the river.

While this process is fundamentally simple it has certain disadvantages which limit its general use. A large quantity of water is required and the effluent discharged contains calcium sulphate in solution. Care must be taken not to saturate any river with calcium sulphate as the water from it would form a scale on heat exchangers in which it might be used. As a result it has been considered unwise to install this process at any other stations in London on the upper or middle tidal reaches of the Thames.

The fact that Thames water is alkaline assists the absorption of sulphur oxides, but if water from other rivers were used, this alkalinity would probably have to be artificially introduced at further cost. No revenue is obtained from the product and it has been estimated that the cost of installing, operating and maintaining this process at a modern power station would be equivalent to an addition of 8 to 10 shillings/ton to the cost of coal burned[4].

Howden—I.C.I. Cyclic Lime Process

When a gas washing process was under consideration for Fulham Power Station the limitations of the Battersea Effluent Process were realised and investigations were therefore carried out to develop a non-effluent process.

In the process eventually devised, the circulating liquor used to wash the flue gas was kept alkaline by the addition of lime. One difficulty which had to be overcome was that of deposition of calcium sulphate on the scrubber packing and this was achieved by adding the lime to the supersaturated solution of calcium sulphate which flowed from the base of the scrubber and allowing the calcium sulphate to crystallize out in a delay tank before pumping the slurry back to the scrubbers. In this way a solution not saturated in calcium sulphate was fed to the scrubbers and the calcium sulphate was removed from the delay tank to a settling and filtration unit.

This process worked successfully for a number of years before it was closed down during the war to prevent conspicuous white plumes being emitted from the chimney; it was not put to work again on the cessation of hostilities due to the estimated high capital cost of renewing the plant. It has been estimated that the all-in cost of this process would be 17 shillings/ton of coal[4].

This process also had a number of disadvantages. The calcium sulphate sludge produced could not be processed to yield any saleable products and had to be taken to sea in barges and dumped. High maintenance costs arose from the fact that solids were being circulated through the scrubbers and corrosion was severe. There was also a potential danger of reducing the availability of the boiler plant due to the choking of the scrubbers.

Origin Of The Fullham—Simon-Carves Process

While both the Battersea and Howden I.C.I. processes successfully removed the sulphur oxides from the gases to the prescribed limits, it was felt that there would be more scope for a non-effluent process producing a saleable product, the revenue from which would off-set the operational costs.

In 1938, the Metropolitan Borough of Fulham approached Simon-Carves Limited and asked them if they could develop a process for manufacturing ammonium sulphate from flue gases, and if they would put forward a design for a pilot plant.

The process proposed by Simon-Carves consisted essentially of scrubbing the flue gases with ammonia

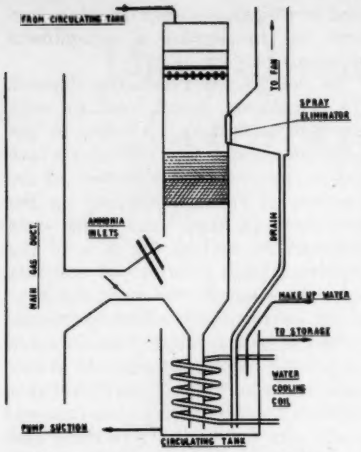

Fig. 1. Fulham pilot plant scrubber.

liquor derived from gas works or coke oven plants to produce a solution of ammonium sulphate, sulphite, bisulphite and thiosulphate, and which, by a process of autoclaving could then be converted into ammonium sulphate and sulphur.

Small scale experiments were first carried out on the central heating plant at the offices of Simon-Carves at Cheadle Heath in 1938. As a result of this work a patent application[5] was made jointly by The Metropolitan Borough of Fulham, Simon-Carves Limited and J. H. Leigh, of Simon-Carves Limited, the inventor.

As the experiments carried out on the central heating plant were largely qualitative, arrangements were made to carry out pilot plant work on a larger scale at Fulham where gases from the power station boilers could be used so that a quantitative assessment of the process could be obtained. This plant was situated in the same power station in which the Howden I.C.I. process was in operation and the work was carried out in collaboration with the Chief Engineer, Fulham Electricity Department, and his staff.

Pilot Plant Work at Fulham

This plant was designed to treat 2000 ft.^{3} of flue gases/min., a rate of flow which was equivalent to $^1/_{64}$ of the total flow from 1 boiler.

It comprised a scrubber unit and an autoclave in which the liquor was processed in batches of about 50 gal. Evaporation of the processed liquor was carried out only on a laboratory scale.

Scrubbing System

A diagram of this scrubber is shown in Fig. 1. It was 2 ft. square in cross-section and about 12 ft. 6 in. high overall. The liquor was fed through ½ in. holes in the head tank onto 4 rows of wooden lathes from which it was distributed to the scrubber packing proper some 3 ft. 6 in. below. Here the liquor was brought into counter-current contact with the flue gases in 2 ft. 6 in. of grid packing.

As will be seen, the scrubber was connected to the main gas duct from the boiler. The gas was drawn through the scrubber by means of a fan in the outlet duct delivering into the gas washer of the existing lime washing system.

The bottom of the scrubber was sealed in a tank which formed a reservoir for the circulating liquor. From this tank, a pump delivered the circulating liquor to the head tank. Water was also fed to the circulating tank to make up for evaporation losses due to the fact that the incoming gas was at a temperature considerably above its dew point. The tank was provided with a cooling coil to control the temperature of the liquor. Another tank was used to receive liquor from the circulation when the desired concentration had been reached.

Concentrated ammonia liquor was received in drums which were emptied into an overhead feed tank and diluted to 10% concentration, the diluted liquor being led to the points of supply in the gas inlet duct of the scrubber.

The quantity of liquor being circulated was measured by an orifice plate, and the gas flow by means of a pitot tube in the scrubber outlet ducting between the scrubber and the fan. Inlet and outlet gas temperatures and pressures, the fan differential and the temperature and pH of the circulating liquor were measured.

The ammonia requirements were gauged by means of a pH recorder working on an acid solution of hydrogen peroxide through which the wet gases were drawn. This solution was buffered to an initial pH of 4.5 to eliminate the effect of CO_2 absorption. Any excess of acid gases (sulphur oxides) lowered the pH while ammonia in excess increased it.

The concentration of ammonium salts in the scrubber was allowed to increase until the composition of the liquor was such that, after autoclaving, it would yield a solution of ammonium sulphate which would be nearly saturated at ordinary temperatures. This concentration would entail the minimum of evaporation to produce crystals but would not crystallise out on storage. When the concentration had built up to this desired amount a quantity was drawn off at a rate corresponding to that at which the ammonium salts were being produced in the scrubber. This liquor was allowed to stand to permit settlement of most of the suspended solids before being fed to the autoclave.

Before autoclaving an analysis of the liquor was carried out to determine the quantity of sulphuric acid which had to be added to ensure that the reaction would proceed as completely as possible to yield only ammonium sulphate and sulphur.

The Reaction in the Autoclave

Liquors produced in the pilot plant scrubber had compositions within the following limits:

Ammonium sulphate	28-24%
Ammonium sulphite	0- 6%
Ammonium bisulphite	0.75- 5%
Ammonium thiosulphate	4-11%

The object of treating the liquor in the autoclave is to convert the latter 3 compounds to yield ammonium sulphate and sulphur. A large number of reactions are possible depending on the relative proportions of the constituents and the conditions under which conversion is carried out. It has been found that, by assuming the principal changes which may occur to be represented by the equations shown below, the quantity of acid required for a given liquor can be calculated.

$$(NH_4)_2SO_3 + 2NH_4HSO_3 \rightarrow 2(NH_4)_2SO_4 + H_2O + S \quad (1)$$

$$2NH_4HSO_3 + (NH_4)_2S_2O_3 \rightarrow 2(NH_4)_2SO_4 + H_2O + 2S \quad (2)$$

$$(NH_4)_2S_2O_3 + 2(NH_4)_2SO_3 + H_2SO_4 \rightarrow 3(NH_4)_2SO_4 + H_2O + 2S \quad (3)$$

$$3(NH_4)_2S_2O_3 + H_2SO_4 \rightarrow 3(NH_4)_2SO_4 + H_2O + 4S \quad (4)$$

It will be seen that ammonium bisulphite will react with both ammonium sulphite and ammonium thiosulphate to produce ammonium sulphate with no other products except water and free sulphur. A liquor having a bisulphite content in the correct proportions to that of sulphite and thiosulphate should be capable of conversion without addition of acid. In actual fact all liquors produced at Fulham had an excess of thiosulphate which required the addition of sulphuric acid before autoclaving.

Autoclaving Unit

The autoclave, shown diagrammatically in Fig. 2, consisted of a mild steel welded cylinder with rounded ends placed vertically and supported on brackets welded to the sides. It was lined with lead, which was carried through into the flanges, and secondly with acid resisting brickwork.

The cover plate had mountings for a thermocouple pocket, a safety valve, a pressure gauge, a vapour release cock and a dip pipe which reached nearly to the bottom of the autoclave. Cocks were fitted to this dip pipe to enable the liquor to be charged or discharged and for steam to be admitted.

The bottom fitment consisted of a steam jacketed discharge mounting and cock.

Liquor was introduced into the autoclave by means of a hand pump, and the acid addition was made through the pyrometer sheath mounting, before replacing it. As direct steam was used to heat the autoclave it was found convenient to restrict the charges to 45 gal. to allow space for the condensed steam, although the volume of the vessel was 95 gal.

Heat was supplied to the autoclave by means of open steam at a pressure of 200 lbs./in.^{2} A temperature of 170°C. was reached on most runs. The steam supply was usually maintained for about 3 hr. and the charge then allowed to cool down overnight, although in a few cases the liquor was blown over from the autoclave after cooling for about an hr. Periodically, after opening the autoclave, the solidified sulphur was broken and removed.

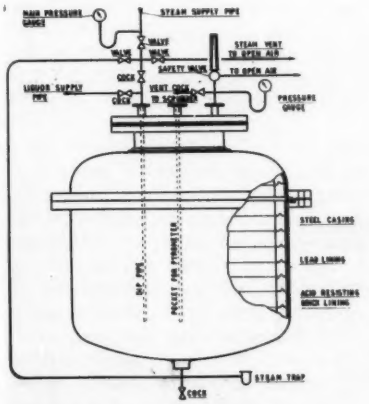

Fig. 2. Fulham pilot plant autoclave.

Results from the Fulham Pilot Plant

Over 3 periods of running, totalling 33 days, the average efficiency of sulphur removal from the gases was found to be 90%. During these periods the average sulphur content of the inlet gases was 0.221 gr./ft.^{3} and the outlet gas 0.022 gr./ft.^{3} This was below the statutory limit of 0.03 gr./ft.^{3} imposed at Fulham.

In the autoclaving step, using the iodine equivalent as a criterion of the degree of conversion of the ammonium salts to ammonium sulphate and sulphur, it was found that a 99.8% efficiency was obtained.

It was found possible to produce ammonium sulphate crystals of a quality which would meet the British Grade I Specification chemically. Since the crystals were produced by evaporation in the laboratory no estimate could be made of their physical structure. It was not anticipated that this would present any difficulty in plant practice.

While the sulphur had only a purity of 96%, this was due to the fact that the liquor had not been filtered in any way before autoclaving and the impurities by their nature had evidently come from the grit in the gases. It was obvious that this trouble could easily be overcome by filtering the liquor.

Further Work on the Development of the Process

In this section mention will be made of further work and investigations carried out subsequent to the work on the pilot plant at Fulham and prior to the construction of the North Wilford plant, which will be described later.

The 1940 Half-Boiler Scale Plant

The experiments with the pilot plant proved that the Fulham—Simon-Carves ammonia process was sound from the chemical point of view and pointed to the necessity for making further investigations on a larger scale to establish the chemical engineering and economic aspects. It was, therefore, decided to proceed in 1940 with a plant to treat half the gases from 1 boiler (approximately 60,000 ft.^{3}/min.).

One of the units used in the lime washing process was suitably modified to serve as a scrubber for this plant. A constant bleed was to be taken from the system at the base of the scrubber and filtered before autoclaving. An evaporator was not provided but arrangements were made with a neighbouring firm to produce ammonium sulphate crystals from the liquor after treatment in the autoclave.

In the pilot plant work, the addition of ammonia to the scrubber had been controlled by means of absorbing the exit gases in an acid solution and measuring the pH of the resultant liquid. While this method was quite successful, the time lag in the apparatus was high and the sensitivity low. In order to overcome these defects an apparatus was built which sampled the gases as before but measured the conductivity of the resultant liquid instead of the pH. It was found that this instrument was more sensitive and reliable than previous ones.

Before this plant could be put into operation the power station and the plant were severely damaged by enemy action. Also, as previously mentioned, flue gas washing had to be discontinued as the plumes of vapour from the chimney made the location of the power station clear from the air. Work on this project was therefore suspended until the end of the war.

Laboratory Work on the Control of the Scrubbing Cycle

As soon as hostilities in Europe were over, plans were again examined for the rebuilding of a plant on a half-boiler scale. In preparation for this it was decided to investigate the control of the scrubbing cycle as it was felt that satisfactory automatic control would be essential for the success of the process.

Dr. Gillham, of the Metropolitan Borough of Fulham Electricity Department, and the author carried out a series of laboratory experiments on the stability of solutions containing varying proportions of ammonium sulphite and ammonium bisulphite. These solutions were made by bubbling gaseous sulphur dioxide into ammonium hydroxide solutions until the desired sulphite/bisulphite ratio was achieved. An air stream was then passed over these solutions under standard conditions, the experiments being carried out in duplicate. One stream was passed through the instrument which was designed for the control of the half-boiler plant and which could detect the presence of sulphur dioxide and ammonia. The other stream was absorbed in acidified hydrogen peroxide and the ammonia and/or sulphur dioxide absorbed was determined.

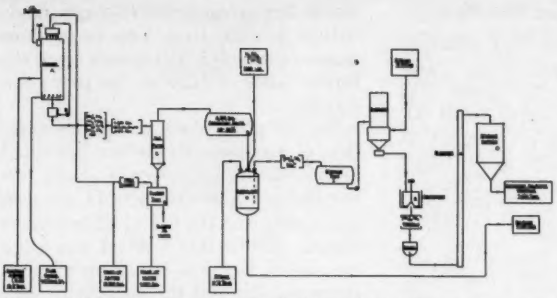

Fig. 3. Simplified flow diagram of Fulham half-boiler plant — time basis 24 hrs.

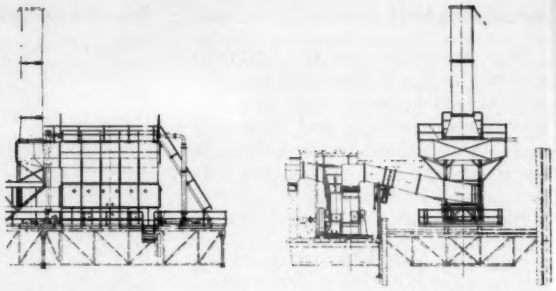

Fig. 5. General arrangement of North Wilford scrubber.

It was found that if air was passed over a solution having ammonia and sulphur dioxide in the correct proportions to produce ammonium sulphite, ammonia was liberated. When the composition corresponded to that of ammonium bisulphite, sulphur dioxide was liberated. At some intermediate composition the minimum loss of ammonia and sulphur dioxide was found.

From these results it was therefore evident that the scrubber could be operated to give the minimum slip of ammonia and sulphur dioxide by controlling the liquor composition.

As an extension of this work an instrument[6] was devised by Dr. Gillham to analyse the scrubber liquor. In this instrument, the sample of scrubber liquor flows down the inside of a tube up which a stream of air passes. The liquor and air rates are both kept steady. As in the experiments just described, if insufficient ammonia has been added to the scrubber liquor, *i.e.* bisulphite predominates, sulphur dioxide will be given off. On the other hand, if too much ammonia has been added, *i.e.* sulphite predominates, ammonia will be liberated. The air stream then passes to an absorption vessel, where it is scrubbed with a dilute solution of sulphuric acid and hydrogen peroxide fed through the apparatus at a constant rate, and led into an electrical conductivity cell. Sulphur dioxide is oxidised to sulphuric acid with a corresponding increase in conductivity. Ammonia combines with some of the sulphuric acid to produce ammonium sulphate and in this case the con-

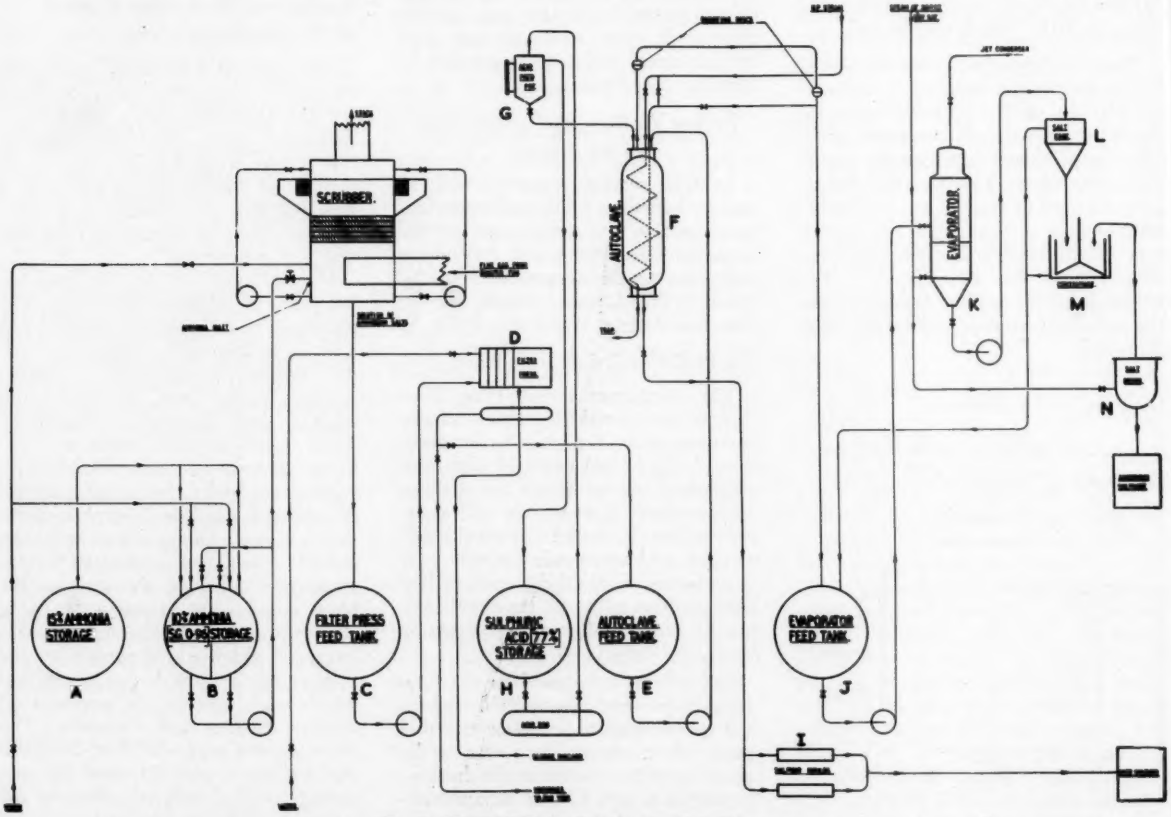

Fig. 4. North Wilford pilot plant — flow diagram.

ductivity is decreased. These changes in conductivity control the current flowing through the cell and this is recorded on a recording milliameter. It can also be arranged for this instrument to transmit a suitable impulse to control the addition of ammonia to the scrubber.

The Proposed Fulham Plant

In addition to the investigations carried out on the control of the scrubbing cycle a new plant was designed to replace the half-boiler scale plant which had been destroyed in 1940. It was proposed to make this a completely self-contained plant capable of producing sulphur and ammonium sulphate crystals. A simplified flow diagram is shown in Fig. 3. It was intended to use again the existing gas washers which had been used for the lime washing process and it will be seen that in addition to filtration and autoclaving units, provision was made for evaporating the liquor to produce ammonium sulphate crystals, which would be centrifuged and dried as in standard ammonium sulphate manufacturing practice. This plant was to take half the gases from 1 boiler and would, therefore, handle the sulphur recovered from the combustion of 150 tons a day of coal containing 1.5% sulphur. Based on previous experience it was anticipated that about 7 tons of ammonium sulphate crystals would be made/day and 11 cwts. of sulphur.

At this time in Great Britain control of capital expenditure occasioned by the war was very strict and no decision was taken to proceed with the building of the plant.

Independent Assessments of the Process

The Fuel Research Station of the Department of Scientific and Industrial Research were also, shortly afterwards, asked to assess the process in relation to others which were being considered and so work was started at the Fuel Research Station in 1949 with this purpose in view.

An account of this work[7, 8] has been given elsewhere and only its bearing on the history of the process will be mentioned here. It was confirmed that the scrubbing cycle could be controlled efficiently by means of the instrument devised by Dr. Gillham and as a result of the work, a favourable report was made upon the process as a whole.

The Committee set up under the chairmanship of Sir Hugh Beaver to study air pollution problems in Great Britain have also investigated possible methods of flue gas washing and pointed out in their final report[2] issued in November, 1954, that this process appeared to them to be promising and likely to be less costly than other known methods.

The North Wilford Pilot Plant

In 1954, the Central Electricity Authority, who had again reviewed the process, decided to proceed with the construction of a plant on the half-boiler scale similar to that which was envisaged for Fulham. The site chosen was at North Wilford Power Station, Nottingham.

The plant has been designed to handle 56,000 ft.³/min. *(actual)* of the flue gases produced by the combustion of coal having a sulphur content of up to 3%. It was estimated that if the liquor composition in the scrubber is similar to that obtained at Fulham up to 11 tons of ammonium sulphate and 2000 lbs. of sulphur should be produced from this plant daily, by working it continuously. The pilot plant is therefore of such a size that it should enable satisfactory cost estimates for a full scale plant to be drawn up from the results. It will also afford an opportunity to find out the best operating conditions and to confirm the design of some of the units.

Plant Description

Flow Diagram

A simplified flow diagram is shown in Fig. 4. 15% ammonia liquor is brought by railway tank wagons and stored in tank *(A)*. This liquor is diluted to a concentration of 10% in tank *(B)* to give a feed at a steady concentration to the flue gas scrubber. The addition of the 10% ammonia liquor is controlled automatically by means of the scrubber liquor analyser described previously.

Flue gas at a rate of up to 56000 ft.³ a min. is taken from the existing ducting in the power station which carries half the gases from 1 boiler. These gases pass upwards through the scrubber in counter-current flow to the liquor.

A bleed of scrubber liquor is taken from the base of the scrubber at a rate corresponding to that at which ammonium salts are produced and this is run to the filter press feed tank *(C)*.

The flue gases are produced in a boiler installation fired with pulverised fuel and pass through an electrostatic precipitator before entering the flue gas scrubber. The scrubber does, however, take out some of the remaining ash from the gases and the liquor from the scrubber is passed through a filter press *(D)* to remove this before being fed to the autoclave feed tank *(E)*. The ash, after washing, is discarded to the power station ash yard.

Liquor from tank *(E)* is fed in approximately 1500 gallon batches to the autoclave *(F)*. Before each batch is processed an analysis is made of the liquor and the correct quantity of sulphuric acid is added to ensure that the reaction will proceed in such a way as to yield only ammonium sulphate and sulphur as the products.

Sulphuric acid (77%) is added to the autoclave from the overhead measuring tank *(G)*, which is supplied by a compressed air elevator from the sulphuric acid storage tank *(H)*. The free space above the liquor in the autoclave is evacuated by means of a vacuum line linked to the evaporator jet condenser and heat is then supplied to the autoclave by means of an internal steam coil to which high pressure steam at a controlled pressure is fed. When the reaction is complete the molten sulphur is run off into sulphur moulds *(I)* and the liquor which will now contain only ammonium sulphate is blown over into a transfer tank using the residual pressure inside the autoclave. If analysis of the liquor shows that the reaction has proceeded successfully it will be transferred to the evaporator feed tank *(J)*, if not it can be re-processed. Provision has also been made in the autoclave for admitting direct steam, as this was the method used in the Fulham pilot plant work. This pipe can also serve as a steam poker if it is desired to agitate the contents of the autoclave.

The ammonium sulphate liquor produced in the autoclave is fed to a standard vertical tube evaporator. The ammonium sulphate crystals produced in the evaporator are pumped to a salt settling cone *(L)*, from which they are fed to a centrifuge *(M)*, where they are washed and partially dried. The crystals then flow to a final steam heated dryer *(M)* from which they are transferred to a small storage hopper feeding a bagging and weighing machine.

The general arrangement of the scrubber is shown in Fig. 5 and 3 sectional elevations of the liquor processing plant in Fig. 6.

Scrubbing System

The way in which flue gases are

supplied to the scrubber is shown in Fig. 5. The flue gases, after passing through the precipitator on the boiler installation are normally drawn through to one of the power station chimneys by means of an I.D. fan. The inlet ducting to the scrubber has been connected to the existing flue gas duct at the outlet of this fan. From this point the gases pass through a booster fan which has been installed to overcome the pressure drop through the scrubbing system. Arrangements have been made so that, if the scrubber circulating pumps or electrostatic precipitators fail, the gases from the boiler will be bypassed directly to the normal chimney. This would ensure that in the case of the first eventuality, the scrubber would not suffer from overheating. In the second case it would prevent fly ash being deposited in the scrubber and possibly clogging parts of the system.

The flow of gases to the scrubber is measured by means of a venturi placed in a straight length of ducting before the inlet of the scrubber. This instrument also controls the gas flow by actuating a louvre damper situated in the ducting after the booster fan. The pressure before and after the scrubber is measured by a differential recorder and the pressure before and after the booster fan on indicating draught gauges. The gas temperatures before and after the scrubber are measured on mercury in glass thermometers.

The gases after passing through the grid packing, where they flow in counter current contact with the scrubbing liquor pass through spray eliminators placed on each side of the washer before passing to the 2 gas outlet ducts, which unite at the base of the washer stack.

The liquor is distributed through a perforated plate in the head tank of the washer before it falls on the grid packing. The bottom part of the scrubber functions as a circulating tank and provision has been made for the liquor to be circulated by means of up to four pumps from the base of the scrubber to the head tank so that a wide variation in liquor rates can be studied. Each liquor delivery line has its own recording flow meter. The temperature and pH of the circulating liquor are also measured.

The addition of 10% ammonia liquor is automatically controlled by means of the liquor analyser already described in Section V 2. A similar instrument is also used to record the sulphur dioxide and ammonia lost from the stack.

The quantity of make-up water added to the scrubber is determined by measurements made on the specific gravity of the liquor. A water meter is available to record the consumption of the make-up water and the rate of flow is indicated by means of a rotameter.

Filter Press

As it was difficult to assess the nature of the material which would require to be filtered from the evaporator, it was decided to install a filter press. This is of the standard plate and frame type and has facilities for washing the cake.

Autoclave

This consists of a stainless steel vessel having a working pressure of 175 lbs./in.^{2} equipped with direct and indirect steam heating and with provision for removing the molten sulphur through a jacketted line.

Steam is supplied from the power station boilers and after being desuperheated is delivered to the autoclave at a pressure controlled by a recording pressure controller. Three resistance thermometers are mounted at different levels in the autoclave and linked to recorders. An automatic

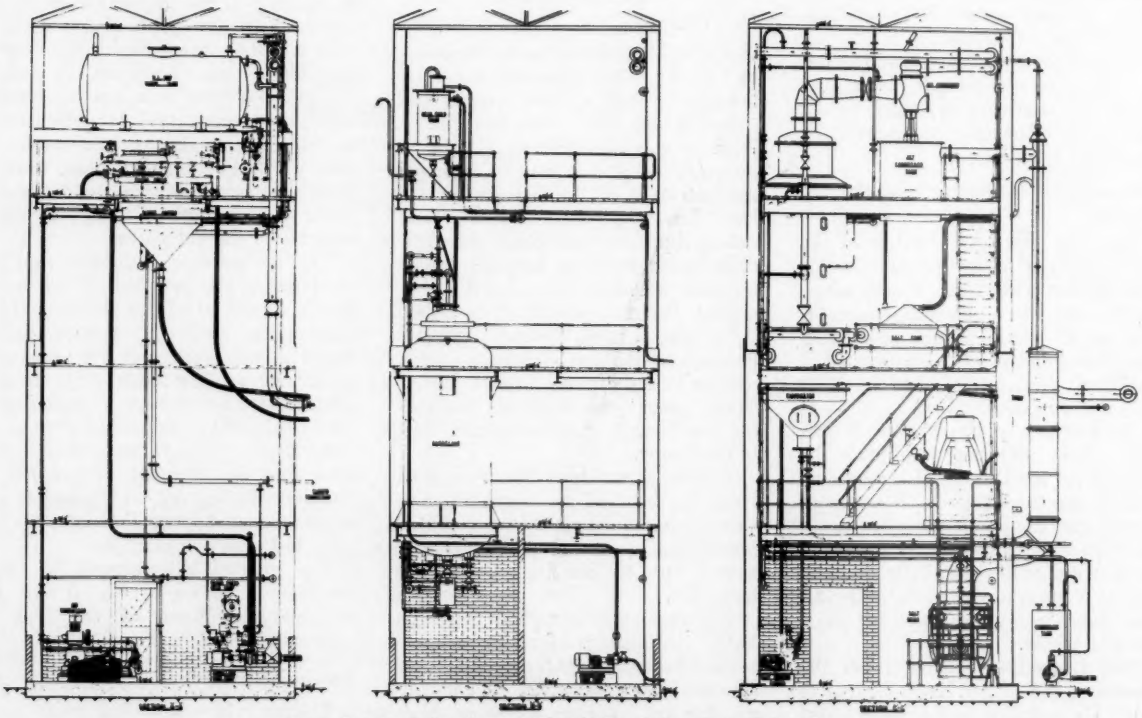

Fig. 6. Sectional elevations of North Wilford pilot plant sulphate house.

record is also kept of the heating steam temperature.

Instead of a safety valve, bursting discs are mounted in a line connected to the autoclave. Should these burst, the liquid would be discharged through an expansion chamber into the transfer tank.

Evaporator Section

The liquor from which the ammonium sulphate crystals are made is fed through a rotameter to a stainless steel, standard, vertical tube evaporator, the calandria of which is heated by means of low pressure steam. The liquor is circulated continuously, rising through 2½ in. diam. tubes and descending through a central downcomer. A vacuum of 27 in. Hg is maintained in the evaporator by means of a combined water ejector and jet condenser. The steam flow to the evaporator is automatically recorded and there are indicators to show the vacuum in the evaporator and the pressure in the calandria.

It is desirable in Great Britain to produce salt of Grade 1 quality as, in addition to the premium price which it commands, it is much easier to wash free from acid and to dry.

The specification is as follows:

(a) SIZE

No lumps to be greater than 4 mm.

Not more than 25% to be greater than 2 mm. (8 B.S.S.)

Not more than 40% to pass through a 30 B.S. sieve.

Not more than 5% to pass through a 72 B.S. sieve.

(b) ACIDITY

Not more than 0.025% free sulphuric acid.

(c) COLOUR

The colour should be uniform.

(d) MOISTURE

Not more than 0.20% (+0.05%) moisture.

(e) NITROGEN CONTENT

Not less than 20.80% nitrogen.

To enable this to be achieved the evaporator must be operated so that the concentration of salts in the bath is about 60% (by apparent volume). A method of salt extraction has been developed whereby this magma can be pumped continuously from the base of the evaporator to the salt settling cone. By this method the ammonium sulphate and the acid in the evaporator are removed in the same ratio as they are present in the feed liquor to it. As a result the acid does not build up in the evaporator, thus minimising possible corrosion troubles. This technique has been successfully developed[9] on ammonium sulphate plants operating at coke oven installations, and differs from previous practice where salt crystals were allowed to settle before removal from the evaporator and where consequently the magma withdrawn contained a lower ratio of acid to ammonium sulphate with a corresponding increase in the acidity of liquor in the evaporator.

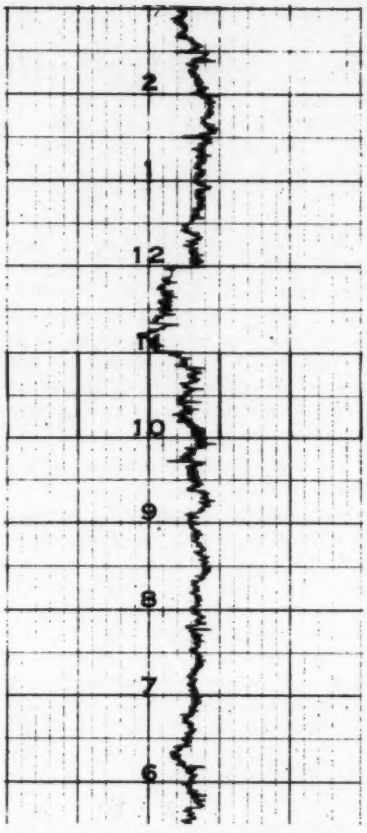

Figure 7. Scrubber liquor analyzer chart.

Provision has, however, been made for any residual acid after autoclaving to be neutralised with ammonia to leave only a very small concentration of acid in the liquor. The mother liquor from the centrifuge can also be similarly treated.

Results from the North Wilford Plant

The plant was commissioned without encountering any major difficulty but, as will be appreciated, in a pilot plant operation minor modifications and adjustments are usually necessary. A number of these are still being dealt with and hence it has not yet been possible to obtain a continuous run such as is necessary to establish a reliable material balance. The effect of changing operating conditions has also not been investigated. However, the preliminary results show considerable promise and a brief summary of these will be given here.

Scrubber

This is handling gases produced in the combustion of coal having a sulphur content of 1.9%. Addition of 10% ammonia liquor is controlled by the scrubber liquor vapour pressure analyser already described, and is made at an average rate of 150 gal./hr. Make-up water to compensate for evaporation is fed in at 360-420 gal./hr. to maintain the circulating liquor at a constant specific gravity of about 1.2. Liquor is bled from the washer at 100 gal./hr. to the processing units. The temperature of the inlet gases is usually in the region of 130°C. and that of the scrubbing liquor, 50°C. Preliminary results with the washer operating at a gas flow rate of 43000 cfm. (actual) and a liquor circulation rate of 1400 gal./min. show a scrubbing efficiency corresponding to approx. 90% sulphur removal.

The overall pressure differential across the scrubber packing and spray eliminators is 1.1 in. w.g.

The liquor vapour pressure analyser/controller is controlling the outlet gas composition satisfactorily. Fig. 7 shows a photograph of a portion of the chart taken from the instrument. The space between each dark line marked in with ink indicates on the right hand side of the trace an excess of sulphur corresponding to approximately 0.005 gr./ft.^{3} (at S.T.P.) over that being passed at the control point. A similar shift to the left of the trace would indicate a corresponding increase in the ammonia slip. The chart records good control.

Filter Press

This is successfully removing the small particles scrubbed from the gases by the liquor.

Autoclave

Nearly complete conversion of the ammonium sulphite, bisulphite and thiosulphate to ammonium sulphate and sulphur is achieved as can be seen from the result shown in Table I.

To ensure conversions during the preliminary period of running, an average of 42.5 gallons of 77% sulphuric acid has been added/1000 gallons of scrubber liquor processed. This is somewhat in excess of the theoretical requirement and the resulting acidity (about 1%) is neutralised after autoclaving by the addition of ammonia liquor in order to feed a liquor of low acid concentration to the evaporator.

Satisfactory runs have been obtained under the following operating conditions:

(a) Heating up (b) Reaction time	1½ hr.
(c) Final reaction temperature	176°C.
(d) Discharging autoclave	2 hr.

However, some difficulty has been experienced in running off the sulphur due to its cooling and modifications are now in hand to jacket the bottom of the autoclave to obviate this.

Products

Data obtained from 13 successive runs on the autoclave show that during this period, the plant produced on the average/day 4.42 tons of ammonium sulphate crystals and 0.67 tons of elemental sulphur.

The quality of the ammonium sulphate is in accordance with the Grade I Specification already defined and no difficulty has been experienced in crystallising in the evaporator system the salt from the auto-claved liquor.

Sulphur of high purity has been obtained from the autoclave, the following being 2 typical analyses:

	1.	2.
Sulphur	99.71	99.95
Combustible matter at about 800°C.	0.09	0.03
Ash	0.03	Nil
Ammonium Sulphate	0.12	Nil
Moisture	0.05	0.02

TABLE I

% w/w	Liquor Before Autoclaving	Liquor After Autoclaving
$(NH_4)_2SO_4$	10.0	35.8
$(NH_4)_2SO_3$	7.4	0.007
NH_4HSO_3	6.1	0.004
$(NH_4)_2S_2O_3$	15.3	0.06

When the modifications to the base of the autoclave already mentioned have been carried out and the procedure for settling and running off the sulphur has been standardised, it is anticipated that sulphur of the quality shown in sample 2 should as a rule be obtained or at least closely approximated.

To date, in the operation of the North Wilford plant, 38% of the total sulphur entering the plant appears as elemental sulphur, in comparison with 24% which would have been predicted from the Fulham experiments. As will be seen from the composition of the scrubber liquors in the 2 cases, less ammonium sulphate is produced in the scrubber at North Wilford, due apparently to less oxidation taking place in the circulating liquor but this feature has not yet been fully investigated.

Costs

Sufficient running of the pilot plant has not been carried out to enable any accurate assessment of costs to be made. Estimates which have been made for the process operating in Great Britain show that, on a full scale plant dealing with combustion gases from coals containing about 1.5% of sulphur, the revenue obtained from the sale of the products should practically compensate for the costs of installation and operation of the plant. If the gases are derived from fuels of a higher sulphur content, the plant could probably run at a small profit. During the limited time the plant has been operating, no undue maintenance work has been encountered and all units and materials of construction appear to be adequate for the duty expected of them.

Acknowledgements

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Emissions from Organic Solvent Usage in Los Angeles County*

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The interest by the Los Angeles County Air Pollution Control District in organic solvent emissions to the atmosphere originated in 1949. It was suggested at that time that hydrocarbons were, in some way, participating in reactions leading to the formation of smog. These reactions consisted of the oxidation of organic material in the presence of sunlight in an oxidizing atmosphere.[1, 2]

Considerable experimentation was undertaken in many laboratories to test the theory. Foremost among these were the experiments of Dr. A. J. Haagen-Smit, of the California Institute of Technology, and APCD workers, who utilized the postulated reactions to prepare synthetic smog mixtures. The similarity between these synthetic smog mixtures and natural smog was demonstrated through their ability to produce eye irritation, damage to vegetation, rubber cracking, natural smog odor, and ozone.[3, 4]

Since pure hydrocarbons or mixtures of hydrocarbons similar to those found in gasoline were used in these experiments, analogous reasoning indicated that organic solvents, which are hydrocarbons and hydrocarbon derivatives, would also be oxidized, resulting in compounds with smog potential. Evidence confirming this has been published independently by Dr. A. J. Haagen-Smit and APCD workers, and the Franklin Institute Laboratories for Research and Development.[5, 6, 7] Some of the organic compounds checked, other than pure hydrocarbons, were alcohols, aldehydes, ketones, acids, mercaptans, chlorinated hydrocarbons and organic nitrogen compounds.

To assess the contribution of these and other organic solvents to the overall air pollution problem, the APCD programmed a series of surveys to yield:

The photographs which follow are intended to accompany the text, and as such, they are not specifically referred to in the body of the paper.

(1) Sources of supply for organic solvents.
(2) Variety and volumes of organic solvents marketed.
(3) Consumers of organic solvents.
(4) Sources of emissions of organic solvents.

Fig. 1. Milling a premixed paint paste to obtain better dispersion. This operation is a source of solvent vapor emission as fresh surface is exposed and the temperature of the paste is raised.

(5) Variety and volumes of organic solvents emitted.

Several of these surveys have already been conducted by mailing questionnaires, making inspections of specific installations and by conferring with representatives of industry. Company lists for the surveys were developed from District files, classified sections of telephone books, Chamber of Commerce listings, trade association membership rosters and other governmental agency licensing and inspection records.

The initial survey which covered the organic solvent suppliers (manufacturers, distributors, jobbers and brokers) identified the purchasers of solvents in Los Angeles County. From this, information was provided for keying in other surveys to the program and pinpointing the sources of solvent emissions. Additional surveys have been of:

(1) Dry cleaners
(2) Rotogravure plants
(3) Paint, varnish, enamel and lacquer manufacturers and distributors
(4) Surface coatings users
  a. Automobile assembly plants
  b. Aircraft companies
  c. Can and container manufacturers
  d. Furniture manufacturers
  e. Appliance manufacturers

In order that all the information acquired through the series of surveys could be evaluated on a uniform basis, a definition of solvent was adopted. Classically, an organic solvent is an organic compound or mixture, usually liquid, which is capable of dissolving other solid, liquid or gaseous substances. The definition adopted by the District required that for a substance to be considered as an organic solvent, it had to be:

(1) an organic liquid, capable of being evaporated or vaporized into the atmosphere

* Presented at the 50th Annual Meeting of the Air Pollution Control Association held at St. Louis, Mo., June 2-6, 1957.

TABLE I

Typical Organic Solvent Uses

Uses	Class of solvents used	Type of solvent action
Manufacture of: Paints, Varnishes, Enamels, Stains, Resins, Shellac Adhesives, Printing inks, Printing pastes, Plastics, Rubber, Gums Rubber cements, Photographic chemicals, Insecticides, Toilet preparations, Other surface coatings	Aliphatic, Aromatic, and Halogenated Hydrocarbons Alcohols Ketones Ethers Esters Misc.	Dissolving Thinning Diluting Dispersing Plasticizing
Cleaning of: Fabrics Metal surfaces	Halogenated Hydrocarbons Aliphatic Hydrocarbons	Cleaning Degreasing
Manufacture of: Paint and varnish removers	Halogenated Hydrocarbons	Surface renovating
Manufacture of: Pharmaceuticals, Glandular extracts Plant extracts, Food extracts	Alcohols Ketones Ethers Esters	Extraction Purification

at the conditions of its usage and storage, and

(2) used to dissolve, dilute, or disperse another substance (or substances) without itself being chemically changed.

Some idea of the diverse uses to which organic solvents are put may be observed in Table I.

It is evident that characterizing an organic chemical as a solvent in one instance does not guarantee that it can always be considered as a solvent. To illustrate, xylene when used as a paint thinner would be thought of as a solvent, but could not be so construed when used as a chemical intermediate for the manufacture of another product. This factor made knowledge of the ultimate uses of each organic chemical necessary in order to prepare solvent loss estimates.

Tabulation of survey data with respect to the variety and volumes of solvents was facilitated by consolidating the more than 200 individual solvent and solvent mixtures marketed into 8 classes. This classification, shown in Table II, fits all of the solvents reported into the classes of aliphatic hydrocarbons, aromatic hydrocarbons, halogenated hydrocarbons, ketones, alcohols, ethers, esters, or miscellaneous. The general chemical formulae and examples of solvents for each class are also shown in Table II.

The principal routes by which solvent vapors enter the atmosphere are natural evaporation or forced vaporization. Some of the operations or situations in which natural evaporation occur are:

(1) Solvent storage vented to the atmosphere.

(2) Manufacture of surface coatings in equipment vented to the atmosphere.

(3) Dry cleaning.

(4) Atmospheric drying of surface coatings.

Vaporization is used to rid a product of solvent in:

(1) Baking and forced drying of surface coatings.

(2) Forced drying of printing inks during rotogravure operations.

(3) Recrystallization and purification of pharmaceuticals.

More detailed information on these processes and the amounts and types of solvents involved will be included in the succeeding sections, which describe each of the surveys made.

Survey of Production and Sales of Organic Solvents in Los Angeles County, 1955-1956

Production and sales volumes of organic solvents in Los Angeles County were obtained by a mail survey of producers and distributors. This survey was conducted during the third quarter of 1956 and, for convenience,

TABLE II

Classification of Organic Solvents

Class name	General formula	Examples
1. Aliphatic Hydrocarbons	R — H	Hexane, Stoddard Solvent, Naphtha, Mineral Spirits
2. Aromatic Hydrocarbons	ϕ — H	Benzene, Toluene, Xylene
3. Halogenated Hydrocarbons	R — X, ϕ — X	Ethylene Dichloride, Trichloroethylene, Perchloroethylene
4. Ketones	$R-\overset{\overset{O}{\|\|}}{C}-R'$	Methyl Ethyl Ketone, Acetone, Methyl Iso-Butyl Ketone
5. Alcohols (and Glycols)	R — OH	Methanol, iso-Propanol, sec-Butanol
6. Ethers	R — O — R'	Ethyl Ether
7. Esters	$R-\overset{\overset{O}{\|\|}}{C}-O-R'$	Ethyl Acetate, Butyl Acetate
8. Miscellaneous Aldehydes, Terpenes, Sulfur Compounds, Nitrogen Compounds, Mixtures	—	Turpentine, Carbon Disulfide, Nitromethane

R or R' — Any straight or branched chain hydrocarbon radical
ϕ — Any benzene ring-type hydrocarbon radical
O — Oxygen Atom X — Halogen Atom
C — Carbon Atom H — Hydrogen Atom

Fig. 2. A paint thinning station where solvents are added to the paint pastes to impart the desired flow qualities and consistencies to the products.

requested the information to be averaged over the year 1955. Statistically, the survey showed sales to the different categories amounting to 356 tons/day of aliphatic and aromatic hydrocarbons, 65 tons/day of halogenated hydrocarbons and 171 tons/day of all other solvents for a total of 592 tons/day.

In all, 76 companies were contacted, covering, it is believed, all producers and distributors, including importers, making sales in Los Angeles County. All 76 companies responded with essentially complete information to the questionnnaire form which was designed to solicit the following information for each organic solvent reported:

(1) Trade name
(2) Chemical name
(3) Boiling range
(4) Flash point
(5) Vapor pressure
(6) Density
(7) Production rate, averaged for 1955
(8) Sales volumes to local buyers, averaged for 1955
(9) Per cents of sales volumes to individual buyers

Tabulation of the data received reveals many interesting facts about solvent usage in Los Angeles County. The identities of the important solvents, solvent suppliers and solvent purchasers, from the view of volumes sold, are all derived from this one survey. Tables III, IV, V and VI summarize these facts.

TABLE III
Identities and Sales Volumes of Most Used Solvents in Los Angeles County, 1955-1956

Solvent	Approximate sales volumes in gal./month
1. Aliphatic Hydrocarbons boiling between 300-400°F.	1,000,000
2. Iso-Propyl Alcohol	— *
3. Ethyl Alcohol	— *
4. Methyl Ethyl Ketone	— *
5. Trichloroethylene	200,000
6. Acetone	— *
7. Methyl Alcohol	— *
8. Toluene	100,000
9. Xylene	100,000
10. Methyl Iso-Butyl Ketone	— *
11. Perchloroethylene	50000
Total for the 11 solvents	2,650,000

*These volumes withheld to avoid release of confidential, competitive data.

In deference to the requests of several of the companies surveyed who supplied their confidential data, precautions have been taken in the public presentation of these data to avoid issuing competitive sales statistics. Table III, therefore, which lists the most important solvents in order of sales volumes gives approximate sales volumes only for the first, fifth, eighth, ninth and eleventh ranking solvents. This method, although not definitive, does bracket the sales volume ranges for the other listed solvents.

In Table IV a comparison of volumes of organic solvents sold by the principal suppliers is given, while in Table V, an analysis of solvent usage is made. Table IV reveals that 9 companies are responsible for sales of about 4,740,000 gal./month or 95% of the total solvent sales. All companies with sales above 100,000 gal./month of solvents were included in Table IV.

TABLE IV
Identities* and Sales Volumes of Largest Organic Solvent Suppliers in Los Angeles County, 1955-1956

Company	Total sales volumes in gal./month
A	1,110,000
B	920,000
C	875,000
D	430,000
E	410,000
F	345,000
G	245,000
H	220,000
I	185,000
Total	4,740,000

*On request, company names are withheld to avoid disclosing competitive positions. This list includes all companies selling 100,000 gal. or more/month in Los Angeles County.

Table V shows that of the almost 600 tons of solvent sold daily in Los Angeles County, the paint, varnish, enamel and lacquer manufacturers purchase the lion's share in all organic solvent classes except that of halogenated hydrocarbons. In that class, the largest single share goes to degreasers. This is illustrated differently in Table VI, which ranks the categories by their percentage of total solvents marketed.

Tables V and VI record only purchases of raw solvents and do not include solvents which are associated or contained in other products purchased such as paints, enamels and adhesives. This note of caution is inserted so as to forestall the equating of purchases by various consumers with their solvent emissions, since in many cases they are not identical. This becomes clear when the losses of solvent from paint, varnish, enamel and lacquer manufacturing are disclosed to approximate only 1 to 3% of the solvents purchased by them. The remaining 97 to 99% is lost at the point of use of such surface coatings and thus should be attributed to the automobile assemblers, aircraft companies and the public. In making these adjustments, it is also important to recognize that a significant percentage of products containing solvents may be exported from the local area so that evaporation of those solvents would occur elsewhere.

Survey of Production and Sales of Paints, Varnishes, Enamels, Lacquers and Other Surface Coatings in Los Angeles County, 1955-1956

Production and sales volumes of paints, varnishes, enamels and other surface coatings in Los Angeles Coun-

TABLE V

Solvent Usage Distribution in Los Angeles County, 1955-1956

Category of user	Usage in tons/day			
	Aliphatic and aromatic hydrocarbons	Halogenated hydrocarbons	Ketones, ethers, alcohols, esters, misc.	Total
Paint, Varnish, Lacquer, and Enamel Mfrs.	150	1	65	216
Dry Cleaners	45	5	(Less than 1)	50
Rubber Products Mfrs.	30	1	2	33
Aircraft Companies	15	1	20	36
Degreasing Operators	5	45	(Less than 1)	50
Service Station Retail Outlets	25	0	0	25
Plastics, Resins, Shellac, Putty Mfrs.	10	(Less than 1)	15	25
Automobile Assemblers	20	(Less than 1)	(Less than 1)	20
Paint and Hardware Store Outlets	10	0	0	10
Gasoline Additive Mfrs.	0	1	15	16
Drum, Can, and Other Container Mfrs.	10	0	3	13
Drug and Pharmaceutical Mfrs.	1	1	10	12
Insecticide Mfrs.	5	0	0	5
Lithographers and Printing Ink Mfrs.	5	0	1	6
Adhesive Mfrs.	0	0	5	5
All others	25	10	35	70
Total	356	65	171	592

ty were obtained through a mail survey of manufacturers and suppliers. This survey was conducted during the latter half of 1956 and requested volumes as averaged for the year 1955. The production of all surface coatings was found to be about 2,700,000 gal./month requiring an organic solvent usage of about 1,300,000 gal./month. About 40% of the surface coating production was exported out of Los Angeles County.

A total of 231 survey letters were sent to companies who classified themselves as manufacturers of one or more surface coatings, including those with a production as low as 200 gal./month. Replies from these companies show that of the 231 contacted, 113 are actively engaged in manufacturing in Los Angeles County and the balance of 118 are either a warehousing operation, a sales office, or are out of business.

Previous information from a trade association that 90% of the total surface coating production could be credited to 10% of the companies was not substantiated by this survey. It was necessary to sum the production from approximately 50 of the largest plants in order to account for 90% of the total production. From this, the inference can be made that more than 50 of the manufacturing plants would have to be equipped with air pollution controls in order to realize any reduction in solvent emissions even approaching 90%. This is predicted on the assumption that surface coatings production and solvent usage are linearly related.

The questionnaire forms for this survey were mailed to each company, requesting the following information, on the basis of average 1955 figures:

(1) Production in gal./month, individually for paints, varnishes, enamels, lacquers and others.

(2) Production sold in Los Angeles County, in per cent, individually for paints, varnishes, enamels, lacquers and others.

(3) Production sold as water-based types, in per cent, individually for paints, varnishes, enamels, lacquers and others.

(4) Production sold for industrial spraying, in per cent, individually for paints, varnishes, enamels, lacquers and others.

(5) Production sold for industrial dip and flow, in per cent, individually for paints, varnishes, enamels, lacquers and others.

(6) Names, volumes and estimated manufacturing losses individually of all organic solvents used in production of paints, varnishes, enamels, lacquers and others, respectively.

The totals of the production and sales volumes of surface coatings manufactured in Los Angeles County during 1955 are given in Table VII.

The volumes summarized in Table VII lead to the following conclusions:

(1) About 60% of the surface coatings produced in Los Angeles County are sold there and the remaining 40% are shipped out of the county.

(2) About 20% of the sales are destined for use in an industrial spraying operations.

TABLE VI

Most Important Purchasers, By Percentages, of Organic Solvents in Los Angeles County, 1955-1956

Category of purchaser	Percentage of total solvents purchased
1. Paint, Varnish, Enamel, and Lacquer Mfrs.	36.8
2. Dry Cleaners	8.5
3. Rubber Products Mfrs.	5.6
4. Aircraft Companies	6.1
5. Degreasing Operators	8.7
6. Service Station and Misc. Retail Outlets	4.3
7. Plastics, Resins, Shellac, and Putty Mfrs.	4.3
8. Automobile Assemblers	3.4
9. Paint and Hardware Stores	1.7
10. Gasoline Additive Mfrs.	2.7
11. Drum, Can, and Container Mfrs.	1.7
12. Drug and Pharmaceutical Mfrs.	1.7
13. Insecticide Mfrs.	1.0
14. Lithographers and Printing Ink Mfrs.	0.8
15. Adhesives Mfrs.	1.0
16. All others	11.7
Total	100.0

TABLE VII
Production and Sales Volumes of Surface Coatings Manufactured in Los Angeles County During 1955

Name of surface coating	Production in gal./mo.	Sales in L. A. County in gal./mo.	Sales for industrial spraying in gal./mo.	Sales for industrial dip & flow in gal./mo.	Sales of water base types in gal./mo.
PAINTS	1,050,000	596,000	42000	12000	322,000
VARNISHES	407,000	210,000	4000	1000	**
ENAMELS	305,000	208,000	80000	17000	**
LACQUERS	450,000	288,000	127,000	6000	**
OTHERS*	472,000	303,000	69000	26000	**
Totals	2,684,000	1,605,000	322,000	62000	322,000

* *Others* comprises stains, sealers, shellac, vinyls, *etc.*
** None or no substantial water base production reported.

TABLE VIII
Volumes of Organic Solvents Used Monthly for Surface Coating Production in Los Angeles County, 1955

Class of solvent	Volume used in gal./mo.
Aliphatic Hydrocarbons	742,000
Aromatic Hydrocarbons	296,000
Alcohols	84000
Ketones	115,000
Esters and Ethers	53000
Others	18000
Total	1,308,000

(3) About 4% of the sales are destined for use in industrial dip and flow operations.

(4) About 20% of the total sales are made up of water-based paints.

About 1,308,000 gal. of organic solvents were purchased for the manufacture of 2,684,000 gal./month of surface coatings shown in Table VII. As some of the companies reporting did not maintain itemized records of the amount of solvents used in each product, only total volumes of each class of solvent are known. These volumes are presented in Table VIII.

If the assumption of a linear relationship between surface coating production and organic solvent usage is correct, then 60% of the 1,308,000 gal. of organic solvents used in the manufacture are present in the surface coatings sold in Los Angeles County. This would amount to about 784,000 gal. of solvent a month which possibly could be released into the atmosphere from surface coating usage.

The solvent losses during the manufacture of surface coatings arise from evaporation from open processing equipment, evaporation during actual processing such as milling, and evaporation from equipment cleaning operations. According to available knowledge, no control of solvent emissions is practiced except for varnish cooking where fumes (which are not principally solvents) from the varnish kettles are incinerated.

The overall estimated loss of solvent in the manufacturing processes is 1.2% by volume, equal to a daily loss of 516 gal. or 1.7 tons, using a weighted average density of 6.7 lb./gal.

Survey of Rotogravure Printing Operations in Los Angeles County, 1956

Seven rotogravure printing plants are now in operation in Los Angeles County with an eighth plant being installed. The survey was conducted in the latter part of 1956, through a series of meetings with representatives of the rotogravure industry and by inspections of their operations. Two of the larger, printing ink manufacturers were also visited to obtain more detailed information about the solvents used in rotogravuring inks.

Gravure printing is a method of printing from a plate into which images have been recessed or etched. Printing is accomplished by inking the recessed images, contacting and transferring the ink from these images in the plate to paper or other material by pressure. In rotogravuring, a horizontal cylinder is used as the plate and its surface with the recessed images is alternately inked and contacted with the paper or material to be printed.

As the printing cylinder revolves, its surface travels through an ink and solvent mixture contained in a trough, encompassing the bottom part of the cylinder. The surface of the cylinder emerging from the *fountain* passes under a doctor blade which scrapes off the excess ink and leaves

Fig. 3. Series of rotogravure printing presses showing dryers, steam lines to dryers and exhaust systems from the dryers. Covered solvent buggies are stationed to the left of the presses.

Fig. 4. Close-up view of rotogravure presses showing the dryers above each press and the covered ink and solvent reservoirs beneath the presses.

Fig. 5. Dry cleaning equipment designed for synthetic solvent usage. Clothes are being loaded into a combination tumbler, extractor and dryer which has a vent to the atmosphere above the solvent vapor condenser. Solvent reclaiming equipment can be seen in the background.

ink only in the recesses. The trough, known as a *fountain* has an overflow pipe to a *reservoir* to maintain a constant level. The ink and solvent mixture is recirculated back to the *fountain* from the *reservoir* by a pump, thus, assuring constant agitation of the ink and solvent.

After contacting the cylinder the paper or other material printed is routed through a dryer, usually using steam heated air. If several colors are to be printed on the same sheet, rotogravuring offers the obvious advantage of a continuous process by having several printing cylinders in series, each with a different color and each followed by a dryer to avoid smearing.

In rotogravure plants, organic solvents are used generally for 2 purposes:

(1) To adjust the viscosities of the printing inks to the levels desired.

(2) To clean equipment.

TABLE IX

Ink and Solvent Usage in Rotogravure Plants in Los Angeles County, 1956

Usage	Average daily amounts* in lb.
1. Printing inks	12400
2. Organic solvent in the printing inks, as purchased	5000
3. Organic solvent added for thinning printing inks and cleaning equipment	15400
4. Total organic solvent used in rotogravure plants	20400

* Based on two 8-hr. shifts/day.

Solvent emissions occur as a result of evaporation from storage, *fountains*, *reservoirs* and equipment cleaning, and vaporization in the dryers.

Some statistics on ink and solvent usage are totaled for the 7 companies in Table IX. From the data submitted it appears that about 25% of the organic solvents used in rotogravuring are associated with the purchased inks. The solvents used consist of 79% of aliphatic and aromatic hydrocarbons and 21% alcohols, ethers and esters.

It is reasonable to assume that all of the solvent used in rotogravure operations will be released into the atmosphere at the plant site, since the printed stock is dried immediately. No control of solvent emissions, other than some covering of solvent containing equipment, is practiced.

To maintain consistency with other loss figures which are averaged over a 30 day month, the organic solvent emissions from rotogravure plants are computed as 7.3 tons/day. About 90% of this amount is contributed by 3 of the 7 plants.

Survey of Organic Solvents Used for Dry Cleaning in Los Angeles County, 1956

Surveys have been made to ascertain the volumes of organic solvents used in dry cleaning operations. Questionnaire forms were mailed to groups of dry cleaning operators, selected at random. Of the 800 plus dry cleaning plants in Los Angeles County, more than 300 have been surveyed.

Each plant was requested to supply the following information concerning their operations:

(1) Average monthly volume and type of organic solvent purchased.

(2) Solvent reclaiming equipment.

(3) Disposal of spent solvent.

(4) Operating schedule for dry cleaning equipment.

(5) Weight of clothes cleaned/month.

Statistically, 60% of the dry cleaning plants use chlorinated hydrocarbons and are known as *synthetic* plants, while the remaining 40% use

TABLE X

Consumption of Surface Coatings Containing Organic Solvents, From the Survey of Surface Coating Users,* Los Angeles County, 1955

Category of Industry	Type of surface coating (gal./month)						Total surface coatings	
	Paints	Varnishes	Enamels	Lacquers	Primers	Misc.**	Gal./Month	%
Automobile Assemblers			54600	65100	61000		180,700	41.4
Aircraft Companies	2300	4500	400	10000	800	12900	30900	7.1
Can and Container Mfrs.		9400	21500	18000		17900	66800	15.3
Furniture Mfrs.		3800	10200	27500	600	10100	52200	12.0
Appliance Mfrs.		400	22100	800	12000		35300	8.1
Job Enamelers			12600	1300	400	460	14700	3.4
Automobile Repainters			5900	2000			7900	1.8
Plastic Product Mfrs.			1200	600			1800	0.4
Miscellaneous***	1600	11400	9100	12900	2700	7900	45600	10.5
Totals	3900	29500	137,600	138,200	77500	49200	435,900	100.0

* Tabulation of the data for the 343 companies using organic solvents.
** Glazes (700), Resins (10,200), Sealer (6,800), Shellac (300), Stain (3,000), Zinc Chromate (10,000), Special Coating (17,900)
*** Electronics, Adhesives, Plating, and Machinery Manufacturer.

Fig. 6. Paint spray booth for automobiles with connected infra-red paint drying oven in the background.

Fig. 7. Close-up of a paint spraying operation showing the spray cone, and the water curtain for capture of solid paint particles. The potential overspray resulting from the spraying of an article with this size and shape is easily visualized.

Fig. 8. Double exhaust, water curtain paint spray station. The water curtain removes solid paint particles from the exhaust gas stream but is a very inefficient remover of the organic solvent.

petroleum solvents and are referred to as *petroleum* plants. Nearly all of the *synthetic* plants have solvent vapor condensation systems integral with the dry cleaning unit, while as a general rule petroleum plants do not have vapor collection. All of the dry cleaning plants possess filtering systems and some operate *muck* (sludge accumulating from the dry cleaning) reclaiming equipment as well. Some of the larger *petroleum* plants also operate their own solvent reclaiming equipment.

The petroleum solvents used are aliphatic hydrocarbons, sometimes referred to as petroleum naphtha, and are either Stoddard Solvent which is used in more than half of the petroleum solvent plants or 140°F. safety solvent. The chlorinated solvents used are perchloroethylene (almost exclusively), trichloroethylene and carbon tetrachloride (to a limited extent).

The smaller dry cleaning establishments, located usually in or near residential shopping areas, use *synthetic* solvents while the larger operators, usually located in industrial or commercial areas, use *petroleum* solvents. Wide variations have been found to exist in the relationship between weight of materials dry cleaned and volume of solvent used, especially amongst the smaller operators. It is quite possible that quantities of solvents in excess of that required are being used and wasted daily into the atmosphere.

Approximate monthly consumption of chlorinated solvents in Los Angeles County is 25000 gal. and of petroleum solvents, 435,000 gal. It is assumed that the amount of solvent purchased and used represents the amount of solvent emitted into the atmosphere. On this basis, solvent emissions from dry cleaning operations are estimated as 5 tons of chlorinated solvent and 45 tons of aliphatic hydrocarbons daily.

The adjustment to be made to these data for the amount of solvent sewered or discarded has not yet been determined. An interesting fact brought out during the survey is that some of the *synthetic* plant operators dilute their chlorinated solvent with petroleum solvent purchased at retail outlets in order to reduce costs.

Survey of Surface Coating Users in Los Angeles County, 1955

The purpose of this survey was to determine the locations of the major surface coating operations and the volumes of coatings and organic solvents used in such operations. In planning this survey, 8 industrial categories plus a ninth miscellaneous category for a variety of smaller industries were chosen on the basis of suspected extensive spray painting, dipping or flow coating operations. The data collected for this survey covered 1955 for the selected industrial companies in the categories of automobile assembly plants, aircraft companies, can and container manufacturers, furniture manufacturers, appliance manufacturers, job enamelers, automobile repainters, plastic products manufacturers and miscellaneous.

A total of 442 individual plant locations in these 9 categories who were contacted by mail and requested to complete a questionnaire form made reply. Of those, only 343 companies were actually engaging in coating processes requiring the use of organic solvents. The companies on the survey list were so chosen as to have, at least, the major companies in each category represented.

The answers to the questionnaire allowed the following data to be accumulated:

(1) Number and types of coating equipment.
(2) Hours of operation.
(3) Air pollution control devices.
(4) Methods of drying.
(5) Coatings applied.
(6) Solvents consumed.

By comparison with data from the *Survey of Surface Coating Manufacturers* and the, as yet, unreported data from surface coating importers, the 343 companies in this survey who are engaged in coating operations involving approximately 436,000 gal./month, account for 84% of the indus-

TABLE XI
Examples of Surface Coating Formulae on An As Purchased Basis

Type of surface coating	Composition of surface coating in %					
	Non-volatile portion	Hydrocarbons		Alcohols	Ketones	Esters and ethers
		Aliphatic	Aromatic			
Paint	44	56				
Varnish	50	45	5			
Enamel	58	10	30	2		
Lacquer	23	7	30	9	22	9
Metal Primer	34	33	33			
Glaze	80		20			
Resin*	50					
Sealer	50	40			10	
Shellac	50			50		
Stain	20		80			
Zinc Chromate	60		40			

* Contains 50% of solvent of an unspecified type.

trial surface coatings used in Los Angeles County.

Table X is a tabulation by category of industry of the types and volumes of surface coatings and organic solvent containing materials used. It also includes the total volume of surface coatings used by each category and per cent of total coatings used by all of the 343 companies reporting surface coating operations. Table XI shows some typical compositions of surface coatings.

Table XII is a tabulation by category of industry of the classes of organic solvents utilized. The original information in gal./month is shown as well as the corresponding calculated result in tons/day and percentage of the total. The calculations were made on the basis of a 30 day month. For the 343 companies, an average of 62 tons of organic solvents are employed daily of which 15 tons are aliphatic hydrocarbons, 29 tons are aromatic hydrocarbons, 5 tons are alcohols, 9 tons are ketones and 4 tons are esters and ethers.

This survey indicates that the 6 automobile assembly plants rank first in usage of surface coatings and associated organic solvents with 41.5% of the total surface coatings and 40.4% of the organic solvents tabulated for all the categories. Three other categories of industries showing substantial usages are aircraft companies, can and container manufacturers and furniture manufacturers. If the additional organic solvents used by these categories of industries for other purposes were added to the results of this survey, aircraft companies would probably show the largest consumption of any of the categories. It is estimated that all of the organic solvents consumed in the surface coating operations of these companies would be emitted to the atmosphere except for the minor amounts now being controlled.

The sources of losses are the evaporation and vaporization of organic solvent during the surface coating application (most commonly by spraying) and subsequently baking or drying. In applying surface coatings by spraying, solvent losses are unnecessarily excessive because of overspray which never impinges on the surface being coated, and so, with its accompanying solvent is wasted. Overspray can amount to as much as 80% or more of the volume sprayed, depending upon the shape and dimensions of the object being sprayed.

Spraying and other surface coating

TABLE XII
Consumption of Organic Solvents in Surface Coating Operations, From the Survey of Surface Coating Users,* Los Angeles County, 1955

Category of industry	Total of organic solvents used in surface coating operations		
	Gal./ month	Tons/ day	% by weight
Automobile Assemblers	213,000	25	40.4
Aircraft Companies	82000	9	14.5
Can and Container Mfrs.	66000	8	13.0
Furniture Mfrs.	57000	7	11.3
Appliance Mfrs.	25000	3	4.7
Job Enamelers	12000	2	3.2
Automobile Repainters	9000	1	1.6
Plastic Product Manufacturers	3000	(<1)	0
Miscellaneous**	61000	7	11.3
Total	528,000	62	100.0

** Electronics, Adhesives, Machinery Manufacturer, and Platers.
* Tabulation of the data for the 343 companies using organic solvents.

applications are uncontrolled and the solvent vapors are exhausted to the atmosphere. The use of water curtains in some spray booths is not considered to furnish control for solvent vapors although a small percentage of the solvent might be dissolved in the water and eventually sewered. The only controls so far adopted for surface coating operations are catalytic combustion units and direct-fired incinerators for baking and drying oven exhaust gases. There have not been enough installations of this kind to achieve any significant reduction in total solvent emissions although local nuisance problems have been alleviated.

Conclusions

Approximately 400 of the 600 tons of organic solvents marketed daily in Los Angeles County are released into the atmosphere. The balance of the 600 tons leaves the county in association with a manufactured product, is consumed in control equipment and is dissipated as liquid or semi-liquid

Fig. 9. Close-up of a vapor degreaser showing a basket of metal parts submerged in the vapor and being degreased by the condensed solvent vapor. The sharp condensation line at the water jacket illustrates how high solvent vapor losses are prevented.

wastes.

The daily emission of 400 tons of organic solvents, as shown in Table XIII, represents 20% of all the organic vapors emitted daily into the Los Angeles County atmosphere. Although later refinements proceeding from other scheduled surveys might alter this relationship by a few per cent, the smog-forming potential and quantity of this large mass of air pollution demand the expenditure of intensive control efforts.

The major sources of organic solvent emissions in Los Angeles County are the aircraft companies, automobile assemblers, rubber products manufacturers and dry cleaners, and the public. If these are classified by type of operation, then the major sources are in the application and drying of surface coatings, degreasing or metal cleaning and dry cleaning of clothes.

No controls are employed for the organic solvents vaporized during the brushing, rolling, spraying or otherwise applying a surface coating, unless the water wash systems used with some spray booths are considered. The primary purpose of such water wash systems is to remove pigment particles from the spray booth exhaust gas stream and any absorption of solvent is inefficient and insignificant.

There are several obstacles to the development of satisfactory control devices or systems. For spray booths, low solvent concentrations and high effluent volumes as well as small amounts of emissions per individual booth present a real economic barrier. For brushing and rolling, the enormous number of small emitters, not located permanently in any one spot, effectively cancel any real hope of an

TABLE XIII
Organic Vapor Emissions*
Los Angeles County, 1955-1956

Sources of organic vapor emissions	Tons/day	%
Automobiles	1200	60.0
Solvent Users**	400	20.0
Incineration	115	5.8
Petroleum Refining	105	5.3
Petroleum Production	60	3.0
Consumer Gasoline Marketing	50	2.5
Petroleum Bulk Marketing	25	1.2
Combustion of Boiler and Heating Fuels	25	1.2
Other	20	1.0
Total	2000	100.0

* Hydrocarbons, Aldehydes, Ketones, Acids, Alcohols, Esters, Ethers.
** Surface Coaters, Dry Cleaners, Degreasers, *etc.*

individual control device. For baking and drying ovens, however, a more optimistic attitude can be taken. Some control installations, operating on a combustion principle, have been made for baking and drying ovens and others are expected. The efficiencies of these are high, better than 90%, where temperatures of the control unit are maintained at a sufficiently high level.

Some types of industrial degreasers may be said to be operating under semi-controlled conditions, in that they employ cooling coils to condense the solvent vapors which might otherwise overflow the equipment. Nevertheless, a portion of the vapors do escape and when added to the losses from other degreasers and degreasing operations create an air pollution problem not to be overlooked. The multitude of small operations with individual small losses, widespread locations and infrequency of many operations hampers quick control.

Synthetic solvent dry cleaning plants are so designed as to condense and recover for reuse a considerable portion of the solvent. Some of the larger petroleum solvent dry cleaning plants also are so equipped but there are more than 200 petroleum solvent plants which are not, and which might prove subjectible to a control program.

In addition to the standard approaches to solvent vapor control by adaptation of activated carbon adsorption, incineration and absorption, other possibilities should also be investigated. Two that would offer an overall, general attack on the problem are:

a. Development of new techniques for applying surface coatings which would necessitate less solvent usage, and
b. Reformulation of products with the present organic solvents substituted for by innocuous solvents.

With regard to new techniques, suggestions have been made to employ heat or pressure to create flowability of surface coatings ordinarily supplied by solvent. Electrostatic spraying has been recommended as a means of reducing overspray and consequent wastage. Another technique, not yet explored, would require enclosure of spraying operation and subsequent reduction of effluent volume and raising of solvent concentration above its explosive limit to make the standard methods of control economically more feasible.

Reformulated products, eliminating the use of organic solvents and replacing them with water, have been in use for many years for household or architectural structure painting. More extensive use of these products, and development of sister products for industrial coatings, would yield returns not only of less air pollution but also of less hazards and possibly lower operating, investment, and insurance costs. A responsible engineer from one of the principal industries applying solvent-based surface coatings stated his opinion, in a private meeting initiated by the APCD, that water-based coatings for his industry would not be commercially available for at least 5 years. There is evidence that development of water-based industrial coatings is being pressed at many companies, with some products already being offered.

Besides reformulation of surface coatings to exclude the use of organic solvents, there are other operations involving the use of organic solvents which would be benefited from an air pollution standpoint. Introduction of non-organic solvent-based degreasing compounds would be one example.

The enumeration of possible control devices and methods gives hope that a reduction of organic solvent losses in Los Angeles County can be attained. With this in mind, studies are being made of legislation applicable to spraying and baking operations of industrial surface coatings. These require more detailed information on several processes and sources in order to define, with more exactitude, the extent of their contributions to air pollution.

Fig. 10. Operation of a vapor degreaser showing how the height of solvent vapor is controlled by a water cooled jacket located near the top of the degreaser. In the particular degreaser shown a liquid solvent rinse is supplementing the vapor degreasing.

Continuing investigations into other industrial categories to establish their types of operations responsible for solvent losses are necessary. Rubber products manufacturing, plastic products manufacturing, drug and pharmaceutical manufacturing are some of the industries intended for future surveys.

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Results of Three Years of Operation of the National Air Sampling Network*

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The National Air Sampling Network had its beginning in 1953 as an investigation to determine by chemical means the amount of protein in pollen and other materials suspended in the atmosphere. After trying a variety of sampling methods, filtration of approximately 70000 ft.[3] of air through an 8x10 in. flat filter over a 24-hr. period was adopted using a vacuum cleaner type exhauster (Fig. 1). Chemical procedures were devised to determine the protein content of the material collected on the filter. Sampling was originally on a weekly basis in most cases, but has very recently been made biweekly.

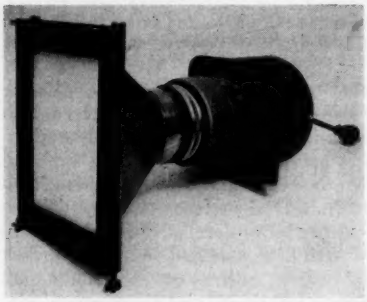

Fig. 1. High volume air sampler.

Air Sampling For Protein Analysis

Since paper filters are organic in nature and may contain protein, it was decided to use glass fiber filters which had just become available in quantities. Flash-firing techniques were developed to burn off the resin binder used in the fabrication of these filters.[1] The resulting filter was free from organic materials and possessed the necessary filtration characteristics. The year 1953 was spent largely in the development of this filter medium, sampling procedures, analytical techniques, and organization of the sampling network in 15 cities (Fig. 2) to field test the method. From the start, all analytical work was done by the Sanitary Engineering Center personnel on samples mailed to Cincinnati by the collecting agency. Originally the filters were folded with the dust-laden size inward, placed in a 4-oz. ointment can, and mailed in a cardboard mailing container, but early in 1955 the procedure was changed to mailing the once folded sample protected by a manila folder in an ordinary envelope of the proper size (Fig. 3).

It was felt that there might be a relationship between the presence of trees, grasses, weeds and other plants, and the pollen-related protein likely to be found in the air. Initial emphasis therefore was on the establishment in each community selected for this field-testing program of at least two sampling sites, one in the business area and another in a suburban or nearby rural residential area with considerable vegetation, the actual number of sites being largely dependent on the ability of the local cooperators to find, maintain, and service several diverse sites. During 1954 and 1955, there were frequent site relocations, as sampler noise proved objectionable in residential neighborhoods, and suburban or rural sites proved inconvenient to service from downtown offices on a routine basis.

Fig. 2. Typical Sampling Site.

Throughout 1954, accumulating data gave evidence of value of the sampling method, weighing technique, solvent extraction steps in the protein analysis procedure, and inorganic analyses as a measure of more general air pollution. However, at that time there was no specific budget in the Service for air pollution studies other than the United States commitment to the International Joint Commission for the Detroit River air pollution reference. Study of the air pollution measurement value of these samples was made by dividing the filter after its initial weighing, so that only a part of it was committed to protein analysis, the remainder being reserved for other measurements (Fig. 4).

Suspended Particulate Loading and Organic Fraction

A preliminary report on suspended particulate levels from several cities for 1953, 1954, and early 1955 was presented in April, 1955.[2] This report included a limited amount of data on the acetone soluble and inorganic portion of the particulate samples. A detailed report on the acetone soluble materials for the same period was presented a month later.[3]

Extraction of samples with benzene provides a more useful product for organic chemical studies than does

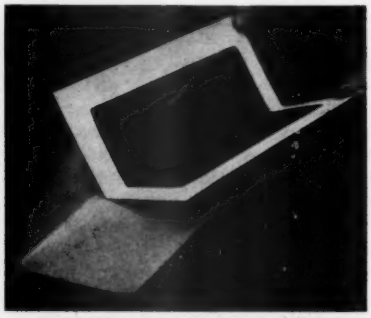

Fig. 3. Typical air sample on receipt.

* Presented at the 50th Annual Meeting of the Air Pollution Control Association held at St. Louis, Mo., June 2-6, 1957.

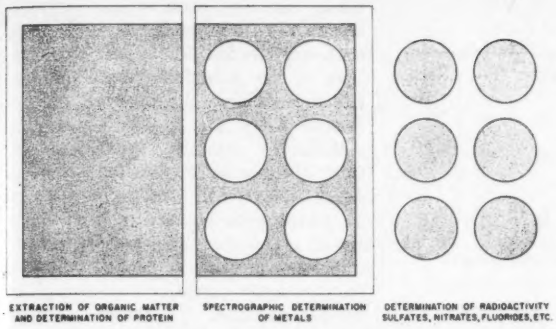
EXTRACTION OF ORGANIC MATTER AND DETERMINATION OF PROTEIN
SPECTROGRAPHIC DETERMINATION OF METALS
DETERMINATION OF RADIOACTIVITY SULFATES, NITRATES, FLUORIDES, ETC.

Fig. 4. Division of sample for analysis.

an acetone extraction, but is less desirable as a preliminary step for protein analysis. The passage of the Federal Air Pollution Research and Technical Assistance Act (Public Law 159 — 84th Congress) in July, 1955, was almost coincident with completion of the research on protein content of air; after that date the solvent used for organic extraction was changed from acetone to benzene and no further protein analyses were made on samples.

The data accumulated on the protein content of air are of only incidental interest to air pollution control officials. For those interested in these data and analytical techniques a report on the protein content of air is available,[4] a condensed version of which will shortly be offered for publication.

Analysis for Inorganic Materials

Under an informal arrangement the Kettering Laboratory of the University of Cincinnati analyzed 784 samples collected during 1953, 1954, and early 1955 for certain metals and anions. A brief summary of these results was reported in an early paper.[2] Since July, 1955 all analysis for metals and anions has been carried out by personnel of the Community Air Pollution Program. These analyses have included a small number of earlier samples, but the bulk of the work has been on 1955 and 1956 samples. The results of the analysis of selected samples from 20 communities for 17 metals were reported in a separate paper.[5] The distribution curves for several of these metals (Fig. 5) show a method of data analysis and presentation using log-probability coordinates, which we believe gives more meaning to range of air pollution measurements than the methods more commonly used heretofore.

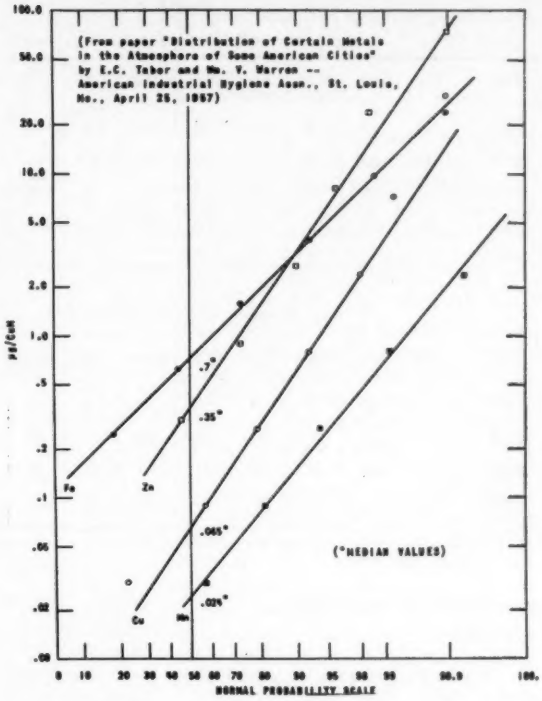

Fig. 5. Distribution of iron, zinc, copper and manganese from 74 samples, 1954-1956.

TABLE I

Radioactivity of Suspended Particulate

Date collected*	Date counted	Sample No.	Sta. No.	Activity/m.³ Alpha** mμμc	Beta** μμc	Beta*** μμc
11/5/54	11/26	1600	A	3	1.09	2.00
11/12	12/13	1926	A	7	2.42	4.00
11/12	12/9	1927	A	11	2.59	4.60
11/18	1/6/55	1928	A	8	1.87	5.20
11/18	1/18	1929	C	7	1.06	3.05

* 24-hr. sampling period
** When counted
*** Extrapolated to time of collection

Composition of Organic Fraction

The quantity of benzene-soluble (*i.e.*, organic) material obtained from an individual 24-hr. sample is too small for detailed analysis to determine its chemical make-up. It has therefore been the practice to pool samples from a sampling site or city to meet the needs of the organic analysts. The number of samples pooled has varied with research needs.

This pooling procedure has the virtue of ironing out day-to-day variations, and the disadvantage of including samples that have aged for weeks or months. The significance of this latter factor is being studied. Evidence to date[6,7] indicates that because of the strong adsorptive properties of the particulate material on hte filter, low boiling point compounds are retained by the particulate matter during transport and storage. There is little or no evidence that any important chemical changes occur during transport or storage of samples, such as to influence the results of the analyses made under the Network program. An initial presentation of the results of separation of the organic material into basic, weak acid, strong acid, aliphatic, aromatic, and oxygenated neutral fractions[8] has already been made.

TABLE II

Number of Sampling Stations in Network*

Year	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.
1953	0	0	0	0	0	0	0	0	2	13	23	31
1954	33	34	36	36	40	42	43	44	46	49	53	56
1955	58	56	59	63	63	62	63	66	62	61	63	64
1956	64	64	62	61	53	51	51	51	47	41	38	32

* In addition special samples, not included in network data, were received from 52 other stations.

Number of Cities In Network**

Year	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.
1953	0	0	0	0	0	0	0	0	2	10	12	15
1954	17	17	18	18	20	21	21	21	22	23	25	25
1955	26	26	31	33	33	35	36	38	38	37	38	41
1956	41	41	43	43	39	39	41	41	38	37	34	32

** In addition during this period special samples, not included in network data, were received from 13 other cities.

Radioactivity of Suspended Particulate

A large proportion of Network samples have from the beginning been measured for beta radioactivity and a limited number for alpha activity. The beta counts have been extrapolated to the time of sample collection to correct for decay. These data are being prepared for publication. In the interim, they are available to those who can use them in the form shown in Table I.

Utilization of Network Data

The publication of the papers mentioned is not the primary method of making network data available to the cities where the samples were taken. The prime method is and will continue to be, the return to the volunteer cooperators, at 3-month intervals, of the raw data from the samples they collected. This information is theirs to use, analyze, or publish separately, as they see fit. The Public Health Service does not edit, review, or restrict such usage of local data, and, although responsible for the analytical accuracy of the data, is not responsible for local interpretation or decisions as to its use.

In view of the mandate of the Air Pollution Research and Technical Assistance Act for the Public Health Service to assemble and disseminate information on air pollution in the United States, we cannot justify making network chemical analyses unless the results are made available to the public. For these data to be most useful to the public, they must be identified by city name rather than by some anonymous label. We believe that such identificatoin will be ultimately beneficial to the cities involved.

Master Plan for the Network

Throughout 1955, while the original network was being converted from a short-term project to a continuing national air quality surveillance network, requests were received from other cities for inclusion. The immediate desire to comply with these requests resulted in a large and somewhat unorganized increase in the number of cities being sampled and in the number of sampling stations within certain cities (Table II), until it became obvious that a more planned development would best serve national needs. Therefore, in March, 1956, a master plan for orderly development and operation of the network was established. It was decided that all new urban sites would be in commercial or business areas, and that residential or suburban area sites would be replaced by nonurban sites as remote as possible from urban influences.

The most difficult change in the Network has been the decision to use only one sampling site/city, a decision taken reluctantly in order to obtain national coverage within existing budget limitations. The analysis by state and local laboratories of samples from more than one sampling site in each major city is strongly recommended. Such local data are needed for fullest exploitation of the data from the local National Air Sampling Network station. Where there are multiple sampling stations in one city, individual station differences are to be expected. Rises and falls of stations tend to be in phase with changes in the diffusional scale; the changes from day to day at each site are large compared to site-to-site variations at any given instant of time. Therefore, a single network site gives information of worth even if the values reported would have been somewhat larger or smaller had another site been chosen.

The master network plan now being followed lists all the major population centers in the United States and sets up a schedule to sample them on an annual, biennial or triennial basis in such a manner that there will be at least one city sampled every year in each state and territory (Fig. 6). The plan further calls for setting up one nonurban sampling station in each state during 1957. We expect to succeed in this goal, and therefore will be activating new nonurban stations throughout the year as rapidly as we can complete arrangements for satisfactory sites on sea, gulf and Great Lakes shores, and in desert, mountain, forest or farmland areas. The plan finally sets forth the analytical workup to be given the samples from each listed city in such a manner that our limited analytical facilities may best be used to develop the national picture regarding air quality.

Periodicity of Sampling

In order to get the desired national coverage, it was decided to switch from weekly to biweekly sampling and to select the biweekly sampling period on a completely random basis. Statistical considerations relating to sample selection have been discussed in detail in a separate paper.[9] An individual sample from a station is almost meaningless. Samples have meaning only when a sufficient number have been obtained in such a wide variety of meteorological conditions that arepresentative range from minimum to maximum diffusion conditions are sampled. A more precise sampling method would be to predict diffusion a day ahead and sample the meteorological range by obtaining a few samples representing each interval between a very stable atmosphere

Fig. 6.

with a minimum of diffusion of pollution away from the ground level to a highly turbulent atmosphere with a maximum of movement of ground level pollution vertically and laterally. We cannot do this because we do not have, at each of over a hundred stations, the equipment, personnel, and know-how for such prediction. An alternative would be to sample daily for 365 days a year and divide the samples on the basis of known meteorological conditions into diffusion intervals. The data would then be analyzed as a grouped or *stratified* sample. This is being done in our Louisville study,[10] but we cannot ask volunteer cooperators to do likewise over the nation. The other alternative, which we have adopted for the Network, is a completely randomized sampling procedure in which we expect by chance to sample all the major ranges of the diffusional scale in successive samples at a given station.

Interpretation of Network Results

The adequacy of a biweekly sampling schedule depends, of course, on the variability of results, but undoubtedly at least a year's operation at any station would be necessary to assure coverage of the range of diffusion conditions. The sampling plan must enable significant changes in source strength to be distinguished eventually from oscillatory seasonal variation. The possibility of such changes can continually be checked by sequential handling of the data in 2 ways: *(1)* plotting successive individual results on log-normal control charts, and *(2)* replotting the continually increasing numbers of observations at annual or semi-annual intervals on log-probability paper to detect changes in geometric means and standard deviations.

It is anticipated that it will take a number of years before effects of changes in source strength will become evident. Since knowledge of changes in source strength is necessary for local air pollution control, for epidemiological correlation and for research planning, we feel that this type of sampling and analysis is basic to the control of air pollution in the United States.

Need for Additional Sampling Techniques

It is recognized that full assessment of air quality requires more information than can be supplied by analysis of particulate collected on filters. Because of this, a concerted effort is being made to develop a means for sampling those pollutants not caught or adsorbed on filters. The method must require no more of the volunteer cooperators' time and attention than does the filter sampler. It also must be inexpensive enough to allow several hundred samplers to be distributed to the network sites for use alongside the filter samplers. As yet, we know of no sampling device that meets the above specifications. Two contractors, the Franklin Institute of Philadelphia, Pennsylvania, and the Pittsburgh Coke and Chemical Company of Pittsburgh, Pennsylvania, and one Federal agency, the National Bureau of Standards, are helping us with this development program.

Future Prospects

A number of agencies operating network samplers have taken advantage of the time between designated sampling periods to take additional samples at the same or different sites. Although our laboratory staff and facility limitations prevent the National Air Sampling Network from undertaking the analytical work on these extra samples, recent changes in our data handling procedures now enable us to process such additional data at minimum effort and expense. These changes have been built around the use of automatic computer technology with punched card input and output, and direct automatic typing of final data tabulations in form for offset reproduction. These tabulations are too lengthy for inclusion here, but will be available in the detailed report of network data from 1953 to date, which is being prepared for distribution.

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Dust and Mist Collection - - A Critique on the State of the Art*

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Fifty years ago the last principal type of dust collection equipment in use today was successfully applied to an industrial program. Dr. F. G. Cottrell in a matter of a few months designed and constructed an electrostatic precipitator for the removal of fumes from the ventilation gases of a gold-silver parting furnace at the Selby Smelter near San Francisco. Even then the concept of electrostatic precipitation was old, probably first being suggested by Hohlfeld in Germany in 1824. In the meantime there had been considerable work carried on on the subject, principally by Sir Oliver Lodge, but Cottrell's use of high voltage direct current finally made the process feasible for industrial application. All other types of presently used dust collection equipment preceded the successful application of electrostatic precipitation. A cyclone, for example, apparently was first patented by Jackson in the 1880's. It found its principal use in woodworking plants until about 1905, when cyclones were utilized for cleaning blast furnace gases. Bag filters are of at least equal age, and probably much older. Even reverse flow filters were in use by 1893. A myriad of scrubber designs were in operation by the turn of the century, and at least one was capable of collecting dust with efficiency equal to that of any in common use today.[3,6,11]

A cursory examination of dust collection equipment available in 1907 might tend to leave the impression that little has been accomplished in the past 50 years. This is, of course, by no means the case, and many improvements in design have occurred in this period.

In the case of cyclones, the major accomplishment has been the recognition that, at least with nonflocculated dusts, efficiency can be improved by the use of small-diameter cyclones. In the case of bag filters, the availability of synthetic fibers in particular has enabled considerable extension of the temperature range in which they can operate. Shaking mechanisms have certainly improved, and reverse jet devices have been made practical for at least relatively large-scale operation. The availability of ultrafine fibers has made highly efficient collection of submicron particles possible with thin filter beds. Scrubbers have shown an increasing tendency toward simplicity of design, and new materials of construction have made them adaptable to highly corrosive services. Electrostatic precipitators have benefited from improved rectification equipment, electrode designs, and rapping mechanisms. Maintenance costs for dust collection equipment in general have probably been very greatly reduced, but there have been no radical improvements in performance, as measured by efficiency, power consumption, and, probably to a large degree, capital investment.

Important as are the advances which have taken place, the increasingly rigid air pollution requirements confronting industrial operations demand better dust collection equipment, from the standpoints of both efficiency and cost. It is, therefore, important to inquire as to why we do not have such equipment available. One reason is that no new principles have been discovered; even the flocculation of aerosols by sound waves was recognized in the nineteenth century. New principles are exceedingly rare, and discovery of them certainly cannot be anticipated with confidence. Another reason is that we are not yet able to predict adequately the performance of even established equipment, much less proposed equipment. Fig. 1,[1] is an illustration of this point. As the inventor conceived the operation of this device, the smoke emerged from the chimney and had an opportunity either to bypass the device completely or to pass over, but not through, a pool of rainwater. The inventor stated only that in passing over the

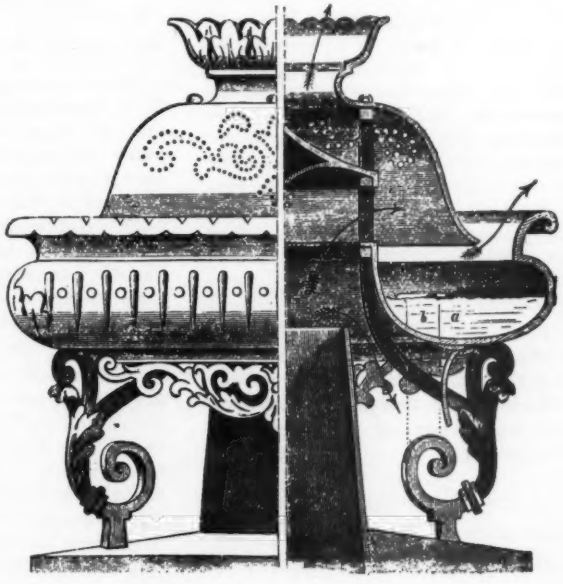

Fig. 1. Victorian dust collector. From an 1869 booklet entitled "The Smoke Nuisance and Its Remedy by Means of Water," by C. J. Richardson, an architect and consulting engineer.[1]

* Presented at the 50th Annual Meeting of the Air Pollution Control Association, held at St. Louis, Mo., June 2-6, 1957.

water the smoke would lose *some portion* of its soot. How much more quantitatively could we predict the performance of even this extremely simple device today?

It might be asked why it is necessary to be able to predict the performance of dust collection equipment. Usually the proposed equipment can be experimentally tested on the dust in question, and selection can be made on the basis of its performance. On the other hand, pilot plant evaluations of dust collection equipment, like any other pilot plant work, can be extremely costly; so this factor alone frequently reduces the variety of equipment potentially available which is actually evaluated in practice. Consequently, one is rarely really sure that the most effective or economic equipment is actually installed. Also, unless pilot plants are operated over a wide range of variables, important trends may be masked by variations in the conditions encountered. Moreover, circumstances may be such that no experimental program is possible prior to the construction of full-scale equipment. However, the most important advantage of prediction of the performance of dust collection equipment is that this would probably provide the greatest opportunity for really substantial improvements in efficiency, power requirements, capital costs, and probably maintenance. The ability to generalize knowledge seems, in fact, to be a fundamental requirement in any field of endeavor if rapid advancement is to be obtained.

Obviously, in order to be able to predict the performance of an actual or proposed design of equipment, we must have a theoretical or at least rational basis for generalizing the factors encountered. Very considerable progress has been made in developing the theory of the mechanisms of dust collection. But much remains to be done, and certainly we have not adequately followed up the theoretical developments which have been made.

It is the purpose of this paper to discuss in a general way the status of theoretical knowledge, the major problems in measurement techniques, and the manner in which these may influence the design, development, and application of dust collection equipment.

Status of Theoretical Knowledge

Mechanisms in Dust Collection

The basic mechanisms operative in any dust and mist collection device may be categorized into 3 distinct phases: *(1)* deposition of suspended particles on a collecting surface; *(2)* retention of the deposit on the surface; and *(3)* removal of the deposit from the surface.

The over-all equipment performance reflects the net composite result of these three phases. The particles must first be separated from the gas stream, which ultimately means deposition of the particles on a liquid or solid surface. Once the particles are deposited on the surface, they may not be considered collected unless they remain there until intentionally removed. If, after deposition, the gas stream re-entrains the deposit, collection has not taken place. The final phase involves removal of the retained deposit from the collecting surface to suitable storage or disposal. In some instances, as in throwaway air filters, this may take the form of physically replacing the collecting surface.

Although some of these phases may appear as relatively trivial physical operations in some instances, they may represent controlling performance limitations in others. For a general and ultimate rationalization of collection equipment design, it is essential that all 3 phases be clearly recognized, as well as any interactions between them. This will be illustrated by some of the specific examples cited in the subsequent discussion.

Deposition Mechanisms

Basic Mechanisms

In order to separate suspended particles from a gas stream, it is necessary to provide *(1)* a force (or pseudo-force, such as momentum change), so directed as to cause a differential motion of the particle relative to the gas, *(2)* a collecting surface upon which the migrating particle can deposit, and *(3)* sufficient gas retention to permit the particle to migrate to the collecting surface.

The 6 known mechanisms by which suspended particles can be caused to deposit on surfaces are summarized in Table I. The inherent effectiveness of deposition by each mechanism is measurable in terms of a dimensionless parameter[4,5,7,8,10,13,14] which incorporates the major aspects of the respective forces and retention times involved as determined by the equipment operating conditions and size scale. This is termed *basic parameter* in Table I. In the case of some mechanisms, the magnitude of the forces involved is also influenced by other factors, related specifically to the mechanism. These factors are termed *specific modifying parameters* and in combination with the basic parameter measure the over-all inherent effectiveness of the mechanism.

Although the above combination of basic and specific modifying parameters measures the inherent effectiveness of each mechanism, the actual deposition efficiency that is realized in a specific application is also a function of additional factors related to the system. The influence of these additional factors may be described or measured in terms of what may be termed *system parameters*. These additional *system* factors and the corresponding *system parameters* are summarized in Table I and discussed below:

(1) Equipment Geometry: Although the scale factor is normally incorporated in the basic mechanistic parameter discussed above, variations in geometric proportions are not. These may be allowed for by respective ratios of salient dimensions to some characteristic dimension or by such terms as fractional solidity in the case of filters or fractional free area in perforated plates or screens.

(2) Fluid Flow Pattern: The basic mechanistic parameter incorporates a gross allowance for flow velocities, but it does not allow for velocity distribution in the equipment. Such distribution effects may have a marked effect. Flow distribution is determined not only by equipment geometry but also by the characteristics of the gas. For incompressible flow conditions (flow of liquids or gases at moderate to low velocities), flow patterns are measurable in terms of Reynolds number, N_{Re}, for a given equipment geometry. Where gas compressibility becomes significant, the additional allowance may be incorporated through the Mach number, N_{ma}. Slip or molecular flow effects are measured in terms of the Knudsen number, N_{Kn}.

TABLE I

Summary of Mechanisms and Parameters in Aerosol Deposition

Deposition Mechanism	Origin of Force Field	Deposition Mechanism Measurable in Terms of		System Parameters
		Basic Parameter	Specific Modifying Parameters	
Flow Line Interception†	Physical Gradient†	$N_{sf} = \left(\frac{D_p}{D_b}\right)$	$N_{sc} = \left(\frac{N^2_{sf}}{N_{si}N_{sd}}\right) = \left(\frac{18\mu}{k_m\rho_p D_v}\right)$ ‖	Geometry: (D_{bi}/D_b), (D_{bc}/D_b), etc.
Inertial Deposition	Velocity Gradient	$N_{si} = \left(\frac{k_m\rho_p D^2_p u_o}{18\mu D_b}\right)$		ϵ_v
Diffusional Deposition	Concentration Gradient	$N_{sd} = \left(\frac{D_v}{u_o D_b}\right)$		a
Gravity Settling	Elevation Gradient	$N_{sg} = \left(\frac{u_t}{u_o}\right)$		Flow Pattern: N_{Re} #
Electrostatic Precipitation	Electric Field Gradient§	$N_{sec} = \left(\frac{k_m Q_p \xi_b}{\mu D_p u_o}\right)$	δ_p, δ_b*	N_{Ma}
	a) Attraction			N_{Kn}
	b) Induction	$N_{sei} = \left(\frac{\delta_p - 1}{\delta_p + 2}\right)\left(\frac{k_m D_p^2 \delta_o \xi_b^2}{\mu D_b u_o}\right)$		Surface Accommodation:
Thermal Precipitation	Temperature Gradient	$N_{st} = \left(\frac{T - T_b}{T}\right)\left(\frac{\mu}{k_m \rho D_b u_o}\right)\left(\frac{k_t}{2k_t + k_{tp}}\right)$	(T_b/T), (T_p/T),* (N_{Pr}), (k_{tp}/k_t), (k_{tb}/k_t),* (c_{hp}/c_h),* (c_{hb}/c_h)*	

* Not likely to be significant contributors.

† This has also commonly been termed "direct interception" and in conventional analysis would constitute a physical boundary condition imposed upon the particle path induced by the action of other forces. By itself it reflects the deposition that might result with a hypothetical particle having finite size but no mass or elasticity.

§ In cases where the body charge distribution is fixed and known, ξ_b may be replaced with Q_{bs}/δ_o.

‖ This parameter is an alternate to N_{sf}, N_{st} or N_{sd} and is useful as a measure of the interactive effect of one of these on the other two. It is comparable to the Schmidt number.

\# When applied to the inertial deposition mechanism, a convenient alternate is $(k_m\rho_p/18\rho) = (N_{st}/N^2_{sf}N_{Re})$.

(3) Particle-Surface Accommodation: It is generally assumed, but not necessarily valid, that a particle will adhere once it contacts a surface. This is probably true for solids contacting solid surfaces at low contact velocities and possibly true for all liquid particles contacting liquid or solid surfaces. It is known, however, that at higher contact velocities solid particles do not all adhere to solid surfaces. In a recent study it was concluded that, at high filter velocities, only 10% of colliding crystalline particles adhered to the filter medium. With large particles, adhesion must be slight relative to removal forces; otherwise pneumatic conveying would be impossible. This raises the probability that in some cases the deposition phenomenon should include an *accommodation* coefficient which is in turn dependent on the physico-chemical properties of both the particle and the surface.

In any collection equipment, all of the above factors are operative simultaneously and a general description of deposition efficiency would require a functional relationship in terms of the various basic mechanistic parameters, their specific modifying parameters, and the various system parameters. Thus, the general case is exceedingly complex. In actual applications, however, only one or a few mechanisms are outstanding or controlling, and the performance can be closely approximated by reduction to the specific controlling factors. We may refer to the field of fluids handling for an analogous situation. Here, also, the general case is very complex, involving effects of turbulence, roughness, hydraulic jump, slip flow, compressibility, *etc.* Yet most applications reduce themselves to one or two simple mechanisms. As in the fluids handling case, however, the simplification in dust collection is possible only with a more or less restricted range of operating conditions. As operating conditions change, the controlling mechanism may change. Thus, the general mechanisms should be kept in mind in order to recognize the cases where this may occur. For example, with filters operated at very high velocity, the controlling mechanism is usually inertial deposition. For operation at low velocities, however, it is probably diffusional. Filter performance characteristics are entirely different for these extreme velocity ranges.

The trade literature presents so-called fractional efficiency curves for cyclones which are simply plots of collection efficiency against particle size. Despite some claims to the contrary, these are applicable only for a cyclone of given geometry, a given size, and given operating conditions. Since cyclones usually operate primarily by the inertial mechanism, such plots can be generalized by presenting them as plots of collection efficiency against the inertial separation number. This is essentially the equivalent of the method of presentation given in Perry's Handbook[12] where collection efficiency is shown as a function of the ratio of particle size to a so-called cut size. The term N_{si} is related to the cut size ratio by

NOMENCLATURE

Any consistent system of units may be used; the absolute metric (c.g.s.) system is shown by way of illustration.

B_c = cyclone inlet width, cm.
c_h = specific heat of gas, (cal.)/(°C.) (g.).
c_{hb} = specific heat of collecting body, (cal.)/(°C.) (g.).
c_{hp} = specific heat of particle, (cal.)/(°C.) (g.).
D_b = characteristic dimension of collecting body or device, cm.
D_{b1}, D_{b2} = other characteristic dimensions of collecting body or device, cm.
D_j = slot width for rectangular jet impactor, cm.
D_p = characteristic particle diam. or dimension, cm.
D_{pc} = particle cut size, cm.
D_v = diffusion coefficient for particle, cm²/sec.
k_m = Stokes-Cunningham correction factor, dimensionless.
k_t = thermal conductivity of gas, (cal.)/(sec.) (cm.²) (°C./cm.).
k_{tb} = thermal conductivity of particle, (cal.)/(sec.) (cm²) (°C./cm.).
k_{tp} = thermal conductivity of collecting body, (cal.)/(sec.) (cm.²) (°C./cm.).
n_e = equivalent number of turns made by gas stream in cyclone, dimensionless.
N_{Kn} = Knudsen number, = (λ/D_b), dimensionless.
N_{Ma} = Mach number, dimensionless.
N_{Pr} = Prandtl number = $(c_h\mu/k_t)$, dimensionless.
N_{Re} = Reynolds number = $(D_b u_o p/\mu)$, dimensionless.
N_{ac} = interaction number = $(18\mu/k_m p_p D_v)$, dimensionless.
N_{sd} = diffusional separation number, dimensionless.
N_{sec} = electrostatic-attraction separation number, dimensionless.
N_{sei} = electrostatic-induction separation number, dimensionless.
N_{sf} = flow-line separation number, dimensionless.
N_{sg} = gravitational separation number, dimensionless.
N_{si} = inertial separation number, dimensionless.
N_{st} = thermal separation number, dimensionless.
N_t = number of transfer units = $\ln [1/(1-\eta)]$ dimensionless.
Q_{bs} = electrical charge surface-concentration, coulombs/cm.²
Q_p = electrical charge on particle, coulombs.
T = characteristic temperature of gas, °C. abs.
T_b = characteristic temperature of collecting body, °C. abs.
T_p = characteristic temperature of particle, °C. abs.
u_c = cyclone inlet velocity, cm./sec.
u_j = jet velocity, cm./sec.
u_o = characteristic velocity of gas in equipment, cm./sec.
u_t = free settling velocity of particle under action of gravity, cm./sec.
μ = gas viscosity, poise.
ρ = gas density, g./cm.³.
ρ_p = particle density, g./cm.³.
δ_o = permittivity of free space, (coulombs)²/(dyne) (cm.)².
δ_b = dielectric constant of body, dimensionless.
δ_p = dielectric constant of particle, dimensionless.
ξ_b = characteristic potential gradient at collecting surface, volts/cm. or (dynes/coulomb).
λ = mean free path of gas molecules, cm.
ϵ_v = fractional volumetric solidity (for granular or fibrous beds), dimensionless.
α = fractional free area, for screens, perforated plates, grids), dimensionless.
η = fractional collection efficiency, dimensionless.

$$N_{si} = \left(\frac{1}{4\pi n_e}\right)\left(\frac{D_p}{D_{pc}}\right)^2 \qquad (1)$$

Fig. 2 shows the performance data given in Perry's Handbook replotted in this fashion.

A fractional efficiency curve generalized in this fashion should be applicable to any size cyclone of the given geometric proportion, and any operating conditions, insofar as deposition is concerned. In making this generalization, various other factors, such as Reynolds number effects, are assumed to be negligible, as is usually the case with cyclones larger than 6 in. in diam. at normal operating conditions. For units of very small diam., however, a Reynolds number effect may be significant. It should be noted here that for curvilinear flow the so-called critical or transitional Reynolds number range is considerably higher than for flow in straight pipes.

For comparative purposes, Fig. 2 also shows the performance data given by Ranz and Wong[13] for rectangular jet impactors used for particle size analysis. As a first approximation, such jets may be looked upon as ¼-turn cyclones. It is interesting to note that the inertial separation numbers corresponding to 50% separation for the cyclone and the jet impactor differ by a factor of approximately 20, which is also the ratio of the so-called *number of turns* in the cyclone to that in the jet. This close agreement is actually circumstantial, since the mechanism is considerably more complex than visualized by a simple number-of-turns concept. It does illustrate, however, the order-of-magnitude agreement between entirely different concepts or approaches.

Conditioning

Deposition mechanisms for given particulate and equipment systems have been considered above, but the actual deposition efficiency that may be attained in a given application may be modified by proper conditioning of the particles or of the collecting surface. Sonic flocculation, for example, is not a deposition mechanism in a practical sense. It is, instead, a means whereby small particles are built up to effectively larger particles that are more readily deposited by the action of one of the mechanisms discussed above.

If the particles suspended in a gas stream to be cleaned are originally in a flocculated state, passing the gas through a duct at high velocity may deflocculate them, making them more difficult to collect. Thus, a cyclone, which should theoretically give a higher collection efficiency at higher gas rates, may actually show a re-

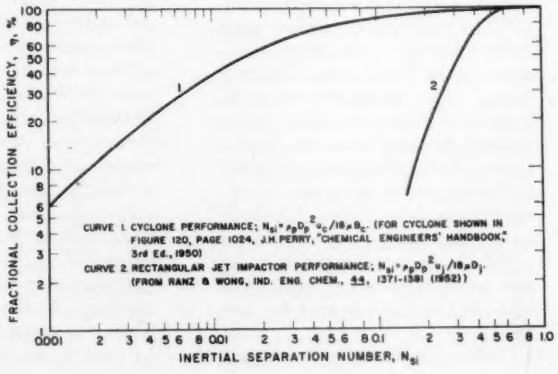

Fig. 2. Performance of inertial separation devices.

verse trend when dealing with flocculated dusts. In this case the cyclone itself is acting as a conditioning agent by deflocculating particles during the collection process. In such cases, it is not that the basic deposition mechanisms are any different, but that another process that reduces the effective size of the suspended particles is superimposed on the deposition process.

Conditioning may take the form of condensing moisture on suspended particles in order to increase their size and make them more readily separable from the gas stream. This is feasible only with relatively low concentrations of very fine particles.

The question of surface accommodation discussed above also raises the possibility of treating either particles or collection surfaces to increase mutual adhesion. In viscous-coated air filters, for example, the fibers are coated with an oil, supposedly to prevent re-entrainment of deposited dust. In the light of recent results, however, it is possible that such a coating may actually serve an additional role in providing for enhanced initial adhesion of particles to the surface during the deposition process.

In the case of mists, passage of the mist-laden gas through a packing at high velocity may result in coalescing the mist particles into large droplets which are then readily collectible in a simple apparatus. The process involves a deposition of fine mist particles on the packing elements, with a subsequent re-entrainment by the gas stream or in a disruptive discharge of coarser drops. The packing, while itself a collecting device, is actually acting as a conditioning agent for subsequent collection devices. Another example in this category is the flocculation of carbon black particles in electrostatic precipitators for subsequent collection in cyclones.

Surface Retention

The fact that particles are deposited on a surface is no assurance that they are collected. To be collected they must remain on the surface, at least statistically. As in the case of the mist agglomerator discussed above, it is possible to have 100% deposition efficiency with 0% collection efficiency.

The problem of retaining a deposit on a surface is basically one of having sufficiently high surface forces to counteract the dislodging tendencies of the fluid shear as it passes over the deposit. Heavy deposits in a filter may be dislodged more readily than light deposits. The attractive surface force on a thin deposit should be essentially the same as for a thick deposit, but the shearing force may increase with the thickness of the deposit. Thus, thick or heavy deposits in filters are more susceptible to dislodgement than thin or light ones. This poses the potential of conditioning either particle or surface to increase deposit retention characteristics. In electrical precipitators, the gradual accumulation of a low conductivity dust on the collecting electrodes results in a potential gradient build-up across the dust deposit. This results either in a reduced electrostatic field strength across the gas strea mor in a disruptive discharge across the deposit which dislodges it. It is to raise the conductivity of the deposit that so-called conditioning is resorted to in operation of electrical precipitators.

Deposit Removal

In any continuous collection equipment, some means must be provided for removing the accumulated deposit either periodically or continuously. In the case of bag filters it is this phase, rather than that of normal collection efficiency, that constitutes the primary engineering design consideration. Although deposit removal is usually purely a problem of mechanical design, it must be considered in terms of over-all collection efficiency. For example, in cyclone collectors, it is common to discharge collected dust through an outlet connected to a screw conveyor, a rotary lock, or simply a flapper valve. Depending on the pressure in the cyclone and the air-tightness of the valve, cyclone collection efficiency can be markedly affected by relatively minute in-leakage of air at the dust discharge hopper.

Current Knowledge

As will be noted from the above, the basic understanding of the mechanisms by which collection equipment functions has been established, with the exception of the nature and magnitude of phenomena involving forces between particles or between particles and surfaces. There are, however, many fundamental areas where more detailed quantitative information is required. It is only in recent years that any significant use has been made of classical hydrodynamics to arrive at over-all theoretical solutions for depositions on simple geometric bodies. The flow pattern in actual collection equipment is usually too complex to permit such direct solutions. However, the idealized solutions for simple systems are exceedingly useful as a guide in predicting the nature and order of magnitude of trends to be expected in actual equipment.

Deep-bed filters represent an excellent example of cases in which classical hydrodynamics has been successfully used to arrive at rational equipment design bases, which are probably more reliable than the ability to assess the basic conditions of any applied problem. Available data on the performance of deep-bed filters have essentially confirmed theoretical predictions regarding liquid or tacky aerosol particles or solid aerosol particles at low infiltration velocities[4, 5, 10]. At high filtration velocities, however, surface adhesive forces play a major superimposed role. The lack of knowledge of this phase is still a major deterrent to quantitative rationalization of collection of solid aerosols in high velocity filters. It is also a major obstacle in quantitative prediction of filter life, where the density of aerosol deposit is governed to a large extent by the equilibrium between surface forces and fluid shear forces.

Although a theoretical solution is highly desirable, it is not essential to an engineering rationalization of the characteristics of collection equipment, and the available theoretical knowledge is adequate to arrive at more rational solutions than have been achieved. Most available equipment investigations have been either highly superficial or restricted to such a specific application that no valid generalization of the results has been possible. From the standpoint of engineering more economic collection equipment installations, reliable information of the following types is sorely needed:

(1) establishment of the controlling performance mechanisms and limitations thereof for the various common types of collection equipment,

(2) establishment of generalized quantitative engineering performance data for the various common types of collection equipment,

(3) establishment of optimum economic design proportions and operating conditions for the various common types of collection equipment.

Attainment of these objectives does not imply assembly of performance data on a wide variety of proprietary equipment. Instead it calls for a critical quantitative evaluation of actual or simulated representative devices to establish important or critical performance trends over all potential operating conditions. Such data may not be quantitatively applicable to any specific proprietary equipment, but they should lead to a basis for criteria by which such equipment may be assessed in any and all applications.

Measurement Techniques

Any basic evaluation of equipment performance, as well as any evaluation of actual field conditions, is beset with a number of measurement problems, some of which are commonly recognized and some of which are not. Particle size is probably the single most important factor in determining how a specific piece of equipment will perform. The most salient measurement problems are associated with the techniques for measuring or determining particle size.

Particle Flocculation

Particulates in gas suspension are flocculated to a greater or lesser extent depending on the material, the concentration, the general size range, and the prior treatment. Flocculation becomes most pronounced with high concentrations of particulates smaller than 10 μ in diam. The performance of the collection equipment is dependent on the effective size distribution of the suspended particles and substantially independent of the ultimate or dispersed size distribution. The methods of particle size analysis commonly used attempt to measure, not the effective size of the particles as they exist in the air stream, but the ultimate or dispersed size distribution, since this is the only reproducible state. Thus, with the many pitfalls normally involved in conventional methods of size analysis, this added question may thoroughly confuse the application to equipment performance. To make matters worse, state of flocculation is not a fixed quantity in a given operation: it may well be influenced by the operating conditions of the equipment itself. This is probably the single major reason for the many conflicting results reported in the dust and mist collection literature to date. To avoid this dilemma, it is necessary, therefore, to develop a means for measuring the effective size distribution of the particles as they exist in the gas stream.

The aerosol camera[2] was one of the first attempts in this direction. It is a device which is capable of photographing aerosol particles *in situ*. In principle this is an ideal solution to the problem. The aerosol camera has, however, the following disadvantages:

(1) It has not yet been developed for use with particles smaller than 2 μ.

(2) It involves relatively laborious counting procedures.

(3) In most cases, to arrive at an effective size from the standpoint of equipment performance, a separate measurement of particle density is required — an experimentally difficult task in itself.

In recent years, a continuous version of a gravity settling chamber has been successfully used in a number of applications to measure the effective inertial particle size distribution. In this device, a particle-laden gas stream is passed through a long, shallow settling chamber at a controlled rate and under streamline flow conditions. The size distribution is calculated directly from a measurement of the deposit gradient in the chamber. This chamber is restricted in its application to measuring effective size distribution in the range of 1 to 50 μ in diam. under laboratory conditions and probably 3 to 50 μ under field conditions. The upper limit is set by inability to reasonably obtain streamline flow for analyses at larger sizes; the lower limit by the predominant effects of convection currents and by excessive gas retention times. A centrifugal adaptation of this device has been designed but not evaluated. This should permit application to effective particle sizes in the range of 0.01 to 10 μ in diam.

Optical methods offer a potential means for measuring effective size distribution without altering the size distribution. They have, however, not been developed to the point where they may be reliably applied to the size range, particle shapes, and particulate concentrations involved in industrial dust collection applications.

Aerosol Generation

For many years there has been general search for so-called *standard* test dusts which can be used to obtain a relative measure of equipment performance. Such dusts can give only relative results and cannot be used to obtain any but crude indications of the way in which particle size may influence equipment performance. Considering the flocculation factor discussed above, even the relative results may prove to be misleading.

To obtain a better representation of the effect of particle size on equipment performance, the trade has in some instances resorted to so-called fractional efficiency curves. These are usually calculated from a comparison of the size analysis of the material fed to the equipment (or collected in the equipment) and that escaping collection. The results of this calculation are very sensitive to the accuracy of the respective size analyses. When one considers the inherent limitations of the size analysis methods used and the superimposed effects of flocculation, one must have implicit faith in one's ability to fair the data in order to arrive at a reasonably reliable fractional efficiency curve by this procedure.

The fractional efficiency curve is, however, a basically sound way of presenting performance data. It is only because of the limitations of current techniques, both in the original evaluation of the curve as well as in the application to field conditions, that this performance criterion has fallen into disrepute in some areas.

A far more reliable procedure is to use uniform or relatively uniform particles in obtaining the necessary test data. The particles in such suspensions should also be essentially completely dispersed. There are essentially 2 methods for achieving such particulate suspensions. One is the controlled vaporization-condensation technique originally proposed by Sinclair and LaMer[16]. This is capable of producing low concentrations of very uniform particles in the size range smaller than 5 μ.

Pneumatic atomization of solutions is another method by which relatively uniform particle suspensions can be generated. Although this technique does not yield entirely uniform particles, the uniformity is sufficient-

ly good for many purposes. This technique is useful for producing particles in the size range of 50 to 0.1 μ, and possibly finer. Size control is also simpler in this technique than in the vaporization-condensation process.

Aerosols generated by the vaporization-condensation technique have been successfully used in evaluation of filter performance characteristics. However, neither it nor the pneumatic atomization technique appears to have been employed to any significant extent in basic studies of the performance characteristics of other types of collection equipment. Both of these methods warrant further consideration and utilization for this purpose.

In other fields, the liquid analog has been successfully used to solve gas phase problems in cases in which direct evaluation with the gas phase presented problems that could be circumvented by using the liquid phase. The use of liquids for evaluating performance characteristics of collection equipment would circumvent the particle size problems, since liquid systems would call for dealing with a larger particle size range. Since particulate suspensions in liquids can be stabilized whereas suspensions in gases cannot, the entire problem of flocculation can be avoided with liquids. Liquid systems will, however, introduce other problems which must be carefully analyzed before considering specific applications for this technique. This technique is worthy of more detailed consideration. It has shown very great promise in applications to cyclone performance made at Ohio State University.

Potential Areas for Development

A number of attractive avenues of approach to development of substantially improved dust collection equipment can already be recognized today. Several years ago, Lapple and Kamack[9] published a paper in which the performance of a number of liquid scrubbing devices of widely varying design was compared, using the same dust dispersions for each equipment. They found that the design of a scrubber had relatively little influence on its collection efficiency and that the latter was primarily a function o fthe pressure drop through the entire scrubber. They also suggested the possibility that the dominant factor in determining the efficiency of a scrubber was the total power expended regardless of whether the power was introduced in the gas phase in terms of gas pressure drop, in the liquid phase in terms of liquid flow rate and pressure required for hydraulic atomization, or by mechanical means. Subsequent work has indicated that this suggestion of a relation between total power expended and efficiency was essentially correct. In our experience there have been only two situations in which a significant deviation from this relation has appeared to occur in the direction of improved collection efficiency for a given power consumption. The first situation was with a particular design of liquid-gas contacting device, and the second occurred when the scrubber was operated under condensing conditions. The relative performances of scrubbers operating under condensing and noncondensing conditions are illustrated in Fig. 3. The data are plotted in terms of total power introduced into the scrubber *vs.* the number of transfer units obtained. The transfer units are a measure of efficiency and more clearly indicate the true increment of performance than efficiency itself. These data were obtained with several types of scrubbers operating on salt cake fume from a kraft paper mill recovery furnace and are treated in more detail by Semrau.[15]. Foth curves represent conditions in which the stack gases were at a temperature of 300°F. and contained a relatively large amount of water vapor. The lower curve represents conditions where the stack gases were contacted with scrubbing liquor at the adiabatic saturation temperature of approximately 150°F. These are the normal conditions under which scrubbers are operated on kraft mill recovery furnaces. The upper curve, however, represents conditions in which the moist stack gases were contacted by a scrubbing liquor consisting of fresh water at a temperature of 70°F. or less. As may be noted, for the same number of transfer units, or efficiency, the contact with cold water reduced the power requirement for the scrubber to only about one-third that required when operating with a hot scrubbing liquor. Such a reduction in power requirement for the large volume of stack gases involved would be of major economic importance.

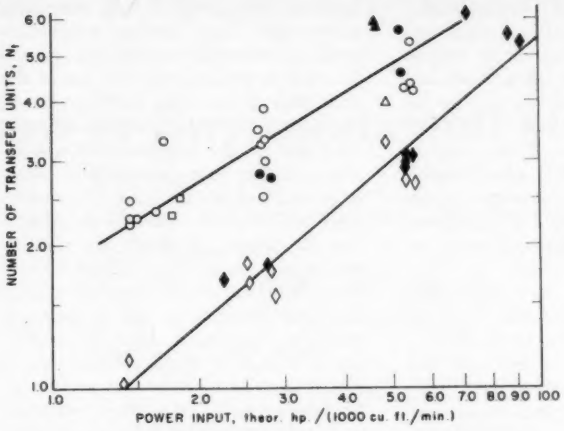

Fig. 3. Performance data for salt-cake fume scrubbers.[15]

Both the concept and usage of condensation as a means of industrial dust collection are quite old. In recent years work has been carried out in which condensation for this purpose was achieved by adiabatic expansion through a nozzle or by injection of steam. The method described above, however, is older, having been used in the Harz Mountains of Germany at a silver smelter in 1909[17].

It should be noted that there was considerable scatter in the data represented by the curves in Fig. 3, and that the improvements obtained could only be detected on the basis of a large number of points. Undoubtedly much of this scatter results from variations in effective size distribution of the dust generated in the furnace from time to time. Also, it may well be that the specific conditions under which condensation is carried out have a major influence on the effectiveness of the condensation. In any event, a systematic investigation of the process, utilizing dusts of a controlled particle size and with adequate methods of measurement of particle size, may well reveal conditions under which substantially better performance than that indicated can be obtained.

Equally attractive opportunities exist in other methods of dust collection. For example, it is known that in bag filters the fabric itself can exert a marked influence on the resistance coefficient of the dust cake. Adequate knowledge of the factors responsible for this phenomenon might permit substantial reductions in the cloth area required for bag filters.

Deep-bed fibrous filters have in recent years become widely used for situations involving very light dust loading, such as in air conditioning. They can operate with high efficiencies on even very fine aerosols and their first cost is attractively low. They have not, however, found particular use for industrial problems where the higher dust loading results in a prohibitively short filter life. Development of practical means of cleaning these filters might well, however, introduce an economic means of treating industrial waste gases containing very fine aerosols. It is even possible that these filters could be used as inexpensive flocculators by operating on a continuous basis. This might be accomplished by designing them so that accumulated dust deposits would shear off in a flocculated state for subsequent collection by cyclones or low pressure drop scrubbers.

Inertial devices such as cyclones are limited in the particle sizes which they can effectively collect by the particle accelerations which can be produced and by the restraining wall friction. Many attempts have been made to increase these accelerations by mechanically driven members, but the potentialities of this method would warrant considerably more attention. Such driven units have great potential for radical reduction of equipment size, weight, and cost when dealing with submicron materials, factors which are of especial interest in aircraft applications.

The dust escaping from electrostatic precipitators is generally flocculated to some degree, and in some instances the escaping dust resembles a snow-fall. These snowing conditions tend to offset the advantages gained in reduced emission by the use of the precipitator, since the settling rate of these large flocs may considerably exceed that of the original dust dispersion. These flocs presumably occur as a result of the shearing of deposits off the electrodes. Where this problem is serious, it might be well to design the precipitator primarily as a flocculator, to reduce the size — and therefore the cost — of the precipitator, as has been done in carbon black collection applications. Much more needs to be known, however, as to the mechanics of surface retention and deposit removal before obtimum constructions can be accomplished and systems designed with confidence.

This by no means exhausts the list of potential improvements in the performance of dust collection equipment. With adequate means of measurement and systematic investigations evaluated on a generalized basis, much more advantage could be obtained from our theoretical knowledge of the existing methods of dust collection, and it is quite likely that such investigations would lead to the development of vastly improved methods which are presently unsuspected.

Summary and Conclusion

Although many improvements in dust collection equipment have been made in recent years, they have been concerned primarily with mechanical details. There has been comparatively little follow-up of the theoretical developments in the design and application of equipment in practice. The single greatest deterrent to engineering rationalization of dust collection equipment design lies in the problems of measurement and interpretation of results. Any evaluation, either fundamental or empirical, which does not fully recognize these problems can yield very misleading results. Wide recognition of these problems, more extensive use of already available techniques for minimization of them, and greater emphasis on development of improved techniques should vastly improve our knowledge of collection equipment performance and should result in more economic and reliable designs and installations. To this end, there is presented a brief general summary of the basic performance principles of dust collection equipment, a discussion of the major problems in measurement techniques, and an indication of specific areas for potential development.

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An Evaluation of Environmental Odors*

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While man has greatly expanded his manufacturing capacities and has concentrated industry within limited boundaries, he has in many cases created contaminated environments. The degree to which this contamination has become a public nuisance depends among other things, upon the concentration and character of the source, the area over which contamination takes place, the residential population of the area, and the atmospheric conditions prevailing in the region. It would indeed be a great day for the Air Pollution Control Association if all potential contamination could be readily controlled and eliminated at the source. While progress has been made in this direction, there are still many industrial processes where control may prove ineffective or too costly, or where public disapproval has not been voiced strongly enough to justify these preventative measures. We must not blame industry alone for this plight, however, since the rapid growth of population in our crowded communities has in itself augmented atmospheric pollution.

From the standpoint of the air-conditioning engineer, it is not his primary concern to evaluate the methods used to control industrial contamination at the source, except possibly where the source and the air-conditioned space are in the same building. He is concerned, however, with the problem of removing from our air-conditioned buildings the outdoor pollution that has entered either through infiltration or through the use of outdoor make-up air in the air-conditioning system. Before the engineer can hope to cope with this problem, a knowledge of the offending contaminant must be realized.

* Presented at the 50th Annual Meeting of the Air Pollution Control Association held at St. Louis, Mo., June 2-6, 1957.

List of Contaminants from City Bureaus

For the past several years, the Air Pollution Control Association has been furnishing the American Society of Heating and Air Conditioning Engineers' Research Laboratory with lists of odorants and contaminants most frequently reported by city bureaus. A tabulation of these data has been prepared and is shown in Table I. The odorants have been divided into the various categories as shown, and only the 3 most frequently reported odorants in each category are tabulated, except in the General Industrial Odors where the 6 most frequently reported odorants are listed.

Under Animal Odors, the meat-packing and rendering-plant odors were the most frequently reported. Fish oil odors, including those from the smoking process, ranked second; and poultry-processes and poultry-ranch odors were ranked in third place.

In the second category (Odors from Combustion Processes), gasoline and diesel-engine exhaust odors were reported most frequently. Coke-oven and coal-gas odors, probably from steel mill operation, ranked second; and fuel-oil odors from maladjusted heating systems ranked third.

In the other categories, coffee-roasting odors, paint, lacquer and varnish odors, hydrogen sulfide, odors of burning rubber from smelting and debonding, foundry core-oven odors, odors from home incinerators and backyard trash fires, mercaptans from refineries, odors of putrefication and oxidation from organic wastes, and odors from city sewers carrying industrial waste were reported the most frequently in their respective groups.

Of all the odors listed, the meat-packing and rendering-plant odors were the most frequently reported. Automotive exhaust odors ranked second, and coffee-roasting odors, paint, lacquer, and varnish odors, and coke-oven and coal-gas odors tied for third place. The odors themselves probably consist of complex compounds of hydrocarbons, nitrides, acroleins, aldehydes, and alcohols.

Some of the odor classes in Table I could possibly be combined. For example, the decomposition and putrefication of organic wastes are probably associated with the meat-processing or fertilizer plants and could therefore be tabulated under these categories.

Although a tabulation of these odors shows which are encountered most frequently, more data (as enumerated at the beginning of the paper) are certainly needed to indicate the degree to which each is responsible for contamination and air pollution in our urban areas.

Methods of Odor Control

Earlier, it was pointed out that the air-conditioning engineer is concerned with outdoor odors that enter buildings through infiltration and through the use of outdoor make-up air. As time passes, however, buildings will be built, so to speak, tighter and tighter; and as indoor odors will ultimately be controlled and removed from the air-conditioning system, the use of outdoor make-up air will be reduced. During many periods of the year, the recirculation of indoor air is, of course, a necessity for the most economy in operation. The goal, where negligible infiltration occurs, is far from being reached however so that outdoor contamination is the concern of the air-conditioning engineer.

Just how do we go about controlling and removing these unwanted odors? In any air-conditioning system, it would be economical to use one unit for the removal of both indoor air-conditioning odors and the odors in outdoor make-up air. Under some conditions, this may not be possible, however. One of the most common methods of removing odorous vapors is by passing the air stream through a bed of activated carbon. The carbon of course has a great affinity for gas and vapors and can adsorb up to ⅓ to ½ of its weight. Several commercial activated-carbon units are now available on the market. The operating life of any unit would depend on the character and concentration of the odorant vapor being adsorbed, and time of exposure. When the carbon is no longer able to adsorb additional malodor, it must either be replaced or reactivated. For best results, the carbon filters should be used in conjunction with mechanical filters and/or electrostatic precipitators. The latter will remove fine particulate matter on which odorous vapors may be adsorbed, but will not in itself remove vapors or gases.

Air washers are commonly used in air-conditioning systems and many water-soluble odors are removed in the process. Likewise, in the dehumidification process of cooling-coils, water-soluble odors are removed along with the condensate. As one theater manager put it, *one can always tell how exciting the motion picture of the previous night was by smelling the body odor laden condensate on the cooling coils the next morning.*

Where outdoor make-up air contains considerable dust, electrostatic precipitators, dry air filters and viscous filters have been employed for the removal of contaminants.

Ozone has been employed as a deodorizing agent and is being used in the control of odors produced by industrial processes. To some extent, ozone has been used in air-conditioned spaces, but as yet, its claim of destroying odors by oxidation needs further investigation, since the action of ozone is not fully understood. Secondary effects such as the fatigue of the olfactory senses and the presence of nitrogen and hydrogen compounds formed in ozone production add to the problem.

Odor masking has been used in reducing the obnoxiousness of odors generated in industrial or chemical processes. Masking agents have not been employed to any great extent in central air-conditioning systems, although some have been used as odor counteractants in individual rooms. The effect caused by the masking agent is that of overshadowing the unwanted odor, or decreasing the sensitivity of the olfactory receptors, or of canceling the obnoxious odor.

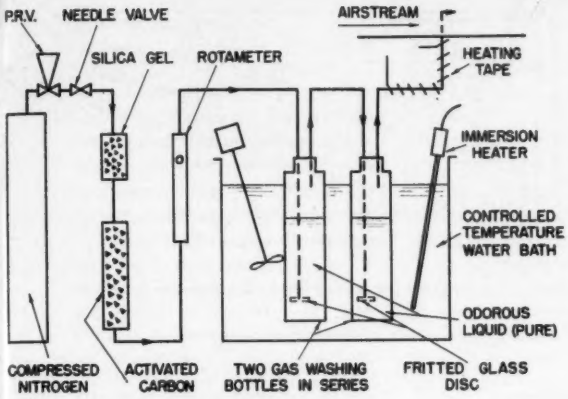
The elimination of odors by catalytic combustion is perhaps the only method that actually destroys an odor. While the method has been employed in the control of industrial pollution at the generating source, it does not have any practical application to comfort air-conditioning systems.

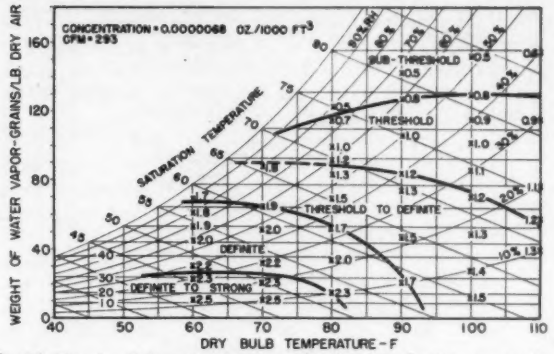
With this brief description of the possible methods used for odor control, it should be pointed out that there is still a great need for further information regarding the performance, applicability, and limitations of these methods. It is only through further research that basic and fundamental answers to odor-control problems can be obtained.

TABLE I

List of Odors Most Frequently Reported by City Bureaus

Source of odor	No. of times reported
I — Animal Odors	
1. Meat packing and rendering plants	12
2. Fish-oil odors from manufacturing plants	5
3. Poultry ranches and processing	4
II — Odors from Combustion Processesffl	
1. Gasoline and diesel engine exhaust	10
2. Coke-oven and coal-gas odors (steel mills)	8
3. Maladjusted heating systems	3
III — Odors from Food Processes	
1. Coffee roasting	8
2. Restaurant odors	4
3. Bakeries	3
IV — Paint and Related Industries	
1. Mfr. of paint, lacquer, and varnish	8
2. Paint spraying	4
3. Commercial solvents	3
V — General Chemical Odors	
1. Hydrogen Sulfide	7
2. Sulphur Dioxide	4
3. Ammonia	3
VI — General Industrial Odors	
1. Burning rubber from smelting & debonding	5
2. Odors from dry-cleaning shops	5
3. Fertilizer plants	4
4. Asphalt odors — roofing and street paving	4
5. Asphalt odors — manufacturing	3
6. Plastic manufacturing	3
VII — Foundry Odors	
1. Core-oven odors	4
2. Heat treating, oil quenching, and pickling	3
3. Smelting	2
VIII — Odors from Combustible Waste	
1. Home incinerators and backyard trash fires	4
2. City incinerators burning garbage	3
3. Open-dump fires	2
IX — Refinery Odors	
1. Mercaptans	3
2. Crude oil and gasoline odors	3
3. Sulphur	1
X — Odors from Decomposition of Waste	
1. Putrefication and oxidation — organic acids	3
2. Organic nitrogen compounds — decomposition of protein Above odors are probably related to meat processing plants	2
3. Decomposition of lignite (plant cells)	1
XI — Sewage Odors	
1. City sewers carrying industrial waste	3
2. Sewage treatment plants	2





(Left) Fig. 1. Schematic drawing of odor introduction apparatus (Pure Vapors). (Above) Fig. 2. Odor perception trends for Isovaleric acid.

The Findings of the Odor-Research Programs

What has the American Society of Heating and Air-Conditioning Engineers been doing to stimulate basic odor research? Besides the program being conducted at the Society Laboratory, papers and reports on the odor problems related to air conditioning are encouraged.

Effect of Temperature and Humidity on Odor Perception

The first phase of the program at the Laboratory has established the effect of temperature and humidity on odor perception[1]. Experiments were conducted in two rooms which were equipped with complete and separate air-conditioning systems for adjusting the temperature and humidity over a wide range. Pure-vapor odorants were introduced into the room supply ducts, and the physical concentration of the odorant within the test rooms was maintained at a constant value for each temperature and humidity condition studied.

Odor Introduction Apparatus

The apparatus used for the introduction of pure odorous vapors consisted of 2 gas-washing bottles in series through which nitrogen was bubbled (Fig. 1). Nitrogen was used in place of air since it was less likely to react chemically with the odorant. The nitrogen was passed through beds of silica gel and activated carbon to remove inherent moisture and odor before it was metered by a rotameter into the bubblers.

The nitrogen leaving the second bottle was saturated with vapor and entered the air-supply duct via a tube, heated with a resistance tape to prevent condensation. The apparatus was constructed of glass, and ground joints were used (after the bed of activated carbon) to prevent contamination. The gas-washing bottles were surrounded by a controlled temperature water bath. The concentration of odorant was calculated from its vapor-pressure properties, the amount of nitrogen bubbled through the washers, and the quantity of air supplied to the test room. The concentration was checked by adsorbing the odorant on activated carbon and measuring the increase in weight.

The odor-perception level in the test rooms for each condition was judged by a panel of 6 persons who entered the rooms and evaluated the perception level by using the intensity scale shown in Table II. The use of these scales is convenient since the word description of the odor level is identified by a numerical value which can be treated statistically. In this scale, a score of 1 was used when the panel member could just identify the quality of the odor. An intensity level between threshold and definite was scored 1½, and so on.

Perception Trends

The results of the evaluations by the panel members for one of the three pure vapors studied is shown in Fig. 2, which is a plot of the mean scores on the psychrometric chart. In this case, the odorant was iso-valeric acid maintained at a constant physical concentration of 0.0000068 oz./1000 ft.³ Each area bounded by the heavy lines represents a constant perception level. Examination of Fig. 2 indicates that an increase in humidity at constant dry-bulb temperature tends to lower the perception level of the odor having a constant physical concentration. In the case of isovaleric acid, this effect appears more pronounced at higher temperatures. Likewise, an increase in temperature at constant specific humidity lowered the perception level slightly, except at higher humidities where a slight reversal appears.

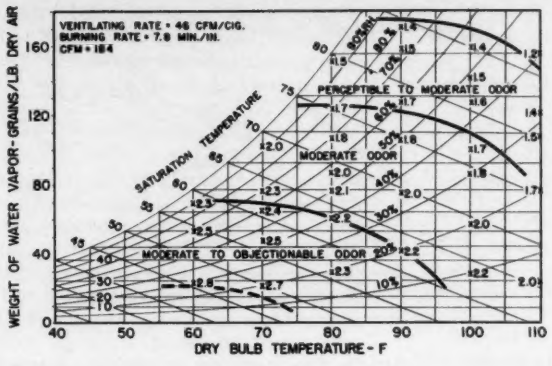
TABLE II

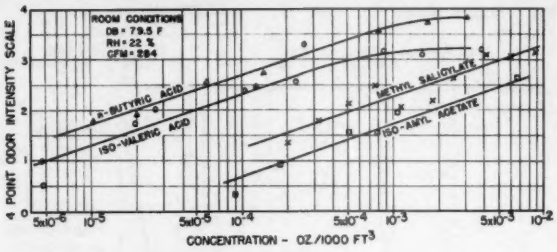
Sensory Scale for Evaluating Intensity Levels

Degree of odor intensity	Description
0	Odorless
1	Threshold
2	Definite
3	Strong
4	Overpowering

Similar evaluations were made on cigarette smoke, and the results are shown in Fig. 3. In this case a slightly different word description was used which seemed more applicable to tobacco smoke. The concentration of cigarette smoke was maintained constant by using 46 cfm. of supply air/cigarette with a fixed burning rate of 7.8 min./in. Here again evaluations of odor intensity made over a wide range of conditions indicate that an increase in humidity at constant dry-bulb temperature tends to lower the perception level of cigarette smoke. Also, an increase in temperature at constant specific humidity tends to lower the perception level slightly.

What do these areas of perception level signify? Referring to Fig. 4, it was found that under a fixed condition of temperature and humidity it was necessary to increase the physical concentration of the pure-vapor odorant tenfold in order to raise the perception level 1 point, and a one-hundred fold increase was necessary in order to raise the intensity level 2 points. Therefore, in Fig. 2, any in-


VENTILATING RATE = 46 CFM/CIG.
BURNING RATE = 7.9 MIN./IN.
CFM = 184
PERCEPTIBLE TO MODERATE ODOR
MODERATE ODOR
MODERATE TO OBJECTIONABLE ODOR
SATURATION TEMPERATURE
WEIGHT OF WATER VAPOR - GRAINS/LB. DRY AIR
DRY BULB TEMPERATURE - F



(Left) Fig. 3. Odor perception trends for cigarette smoke.

(Above) Fig. 4. Odor intensity vs. concentration.

crease in humidity that lowers the perception level 1 point has the same effect as lowering the concentration by 90%.

It certainly would be ideal from the standpoint of lowering the odor-perception levels if all we had to do were to increase the humidity of our environments. However, the problem is not so simple. For one thing, one has to consider the comfort of the persons in the environment. The problem is further complicated by some of the findings of Dr. R. L. Kuehner. Although Dr. Kuehner[2] has verified our conclusion that the perception level decreases with an increase in humidity, he has shown that under humid conditions some substances (linoleum, for example) will actually liberate more odorant. All of us have experienced the effect of getting on a crowded bus on a warm rainy day. The odor from the damp clothing is quite noticeable, resulting from an actual increased rate of odorant production. It would appear then that nature has been wise in giving our olfactory senses a built-in safety factor by lowering our perception acuteness under humid conditions when the rate of odorant production is increased.

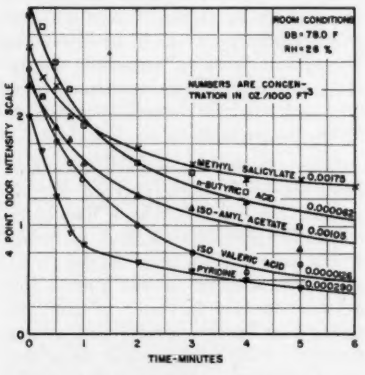


Fig. 5. Adaptation to pure-vapor odors.

Odor Adaptation

Exposure to odors over a period of time can cause a decrease in perception level. What actually happens is that the odor receptors in the nasal passages become fatigued. We can probably recall the experience of entering an occupied room that was noticeably stuffy with body odor, and then after a period of time, realizing that the perception level had decreased. For this reason, an individual is not aware of his own breath or body odor simply because he has become adapted to it.

To illustrate the effect of odor adaptation, the panel members were exposed to a constant physical concentration of odorant for a given period of time. The member entered the test room and sniffed immediately for an initial impression. Breathing normally through the nose, judgments were made every 15 sec. for the first minute and every minute thereafter for a maximum of 6 min.

Fig. 5 gives the results for a number of pure vapors. Each point represents the mean score of 6 to 8 judges. The concentration was adjusted to give initial readings between 2 (definite) and 3 (strong). In all of the tests, adaptation was greatest during the first stages of exposure. The curves for iso-valeric acid and n-butyric acid are nearly the same shape (although displaced), indicating an identical adaptation rate. In all of the tests, the conditions were maintained at 78°F. dry-bulb and 26% RH.

Tobacco smoke is one of the major odorants that one encounters in air-conditioned spaces. While one can become adapted to the odor of tobacco smoke, the irritation to the eyes, nose, or throat generally increases with time of exposure. The results of evaluations made by panel members exposed to cigarette smoke over a given period time are shown in Fig. 6. Here we find that the initial impression is to rate the odor level high and the irritation level low. With time of exposure, however, the odor-perception level decreases while the irritation level rises. Again we find that at higher humidities (above 50%) the levels are lower than at lower humidities (below 35%).

Besides the problem of removing common odors in occupied spaces, another serious problem arises. Surfaces have a tendency to adsorb odors (especially when cool) and reliberate them when warm. For complex odors such as cooking, body, and tobacco odors, the most obnoxious components appear to be the ones most readily adsorbed. The adsorption on the surfaces of the cooling coils and the duct work of the air-conditioning system is in itself an odor source when *unloading* occurs. Mr. A. B. Hubbard and his co-workers have investigated a number of materials and coated surfaces used in coil construction.[3] The materials were subjected to controlled-generated odors and were then evaluated by panel members for their pickup and

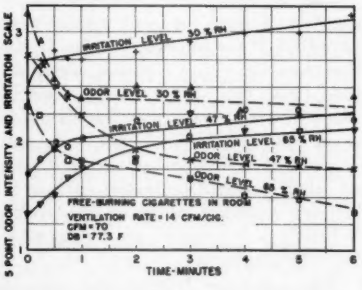

IRRITATION LEVEL 30 % RH
ODOR LEVEL 30 % RH
IRRITATION LEVEL 47 % RH
IRRITATION LEVEL 65 % RH
ODOR LEVEL 47 % RH
ODOR LEVEL 65 % RH
FREE-BURNING CIGARETTES IN ROOM
VENTILATION RATE = 14 CFM/CIG.
CFM = 70
DB = 77.5 F
5 POINT ODOR INTENSITY AND IRRITATION SCALE
TIME-MINUTES

Fig. 6. Adaptation to cigarette-smoke odor, and irritation caused by cigarette smoke generated in room.

purging-rate characteristics. The best materials were those which exhibited little pickup and then purged or reliberated the adsorbed odors rapidly. Aluminum was found to be one of the best materials, while bare copper exhibited the poorest qualities.

At the present time, the odor-research program is continuing at the ASHAE Laboratory where the odor adsorption and desorption qualities of fabrics and building-material surfaces are being evaluated. In this study, a bottle technique is being used for odor evaluation. Samples are loaded with odorant and placed in bottles after specified periods of airing. Human subjects then evaluate the odor levels in a set of bottles (one set for each airing time) containing varying sample sizes until a threshold level is reached. This level is fixed by the ratio of bottle volume to sample area. This gives a definite tangible number that can serve as an index to predict the degree of odor level in rooms and occupied spaces where the wall surfaces, draperies, or rugs are exposed to odorants. A plot of this $\frac{V}{A}$ ratio versus the airing time for various materials will show the ones that *unload* the most rapidly and the ones that adsorb the most odorant (zero airing time).

A representative range of fabric surfaces including cotton, wool, and synthetics will be studied. While pure vapors will first be used, the ultimate aim of the program is to investigate the effect of common air-conditioning odors such as tobacco smoke. After fabric surfaces are investigated, attention will be turned to painted and other types of building-material surfaces. In the present study, a fixed condition of temperature (75°F. dry bulb) and humidity (50% RH) is being used for loading, airing, and evaluation of the sample. A future phase of the program (probably in 1958) will be to determine the effect of temperature and humidity upon adsorption and desorption characteristics.

One can see that the odor-control problem in air-conditioned spaces has many facets, as does the control of outdoor air pollution. It is only through the cooperation of research and industry and perhaps the longing to breathe the pure air which nature has given us, that progress can be made toward clean and odor-free environments.

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A Progress Report on Controlling Atmospheric Pollutants*

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A review of the air pollution control activities in 1957 shows an impressive record of six million dollars expended in research, over 200 governmental agencies assigned to some measure of responsibility for clean air in their communities, and annual sales in control equipment and engineering services well in excess of one hundred million dollars.

On this Fiftieth Anniversary of the Air Pollution Control Association, the impression is clear that present day interest in this subject can be found, to some degree, in every community and industry in the nation. It is not easy to find the forces which have created this relatively new activity. Certainly, it can be shown that in the past 50 years, our population has doubled and this, in itself, represents a significant factor in the many pressures which have created the demand of today. The production of electrical energy is an index of fuel requirements and of our industrial growth. Since 1930, coal consumption for power is up more than 250%, fuel oil more than 700%, and gas burning, 800%. Thus, the requirements for new products to supply our increased population and the technological changes which have led to a higher standard of living constitute fundamental pressures to create air pollution problems.

It is doubtful, however, if these factors in themselves would have brought us to this point today without the Donora episode in 1948, the London disaster in 1952, and the effect that the Los Angeles smog problem has had on this subject since 1948. Prior to these events, no general interest in total air pollution control existed. Efforts, traditionally, had been directed against smoke from coal burning operations. Local nuisances near smelters and cement plants occurred in several instances, but these served only to generate local interest on the part of the community, and some effort at control measures on the part of the industry involved. It is from these local incidents, however, that today's control measures find their origin.

Sulfur Dioxide

Pioneering work on sulfur dioxide, by the American Smelting and Refining Company, was undertaken, to reduce ground concentrations, in the early part of the 20th century. The data accumulated from these studies is largely responsible for the support now given to the building of tall stacks to avoid damage to forage and other crops and thus, obviate severe economical losses to farming areas in the vicinity of sulfur dioxide producing installations. Early examples of the success of this approach are to be found at smelters in Utah, California, Washington, and Texas.

The economical recovery of valuable sulfur compounds, from sulfur dioxide emissions, has been of great interest to industry and researchers for many years. The huge tonnages of this contaminant which reach the air from the combustion of fuels containing sulfur and from the processing of sulfur bearing ores may ultimately justify expensive recovery processes to augment the great demand for sulfur. The most recent development of economic importance in this field is the recovery of sulfur from refinery gases. Wherever sulfur bearing crudes were being processed, prior to 1950, the hydrogen sulfide remained in the refinery *make gas* and was burned in the boiler or flares of the refinery. At the present time, more than 2000 tons/day of sulfur dioxide are prevented from reaching the atmosphere and the recovered 1000 tons/day of sulfur are returned to the acid plants near refineries for sulfuric acid production. This process converts the hydrogen sulfide removed from the refinery gases to sulfur, by the controlled combustion of air, in which $\frac{1}{3}$ of the H_2S is burned to form SO_2, which reacts with the remaining $\frac{2}{3}$ H_2S to form sulfur and water vapor.

Some years ago extensive damage resulted from sulfur dioxide from a smelter in Trail, B. C. Here, the ammonia sulfite bi-sulfite process was found to be economically successful, with stack concentrations of sulfur dioxide above .8%. Also, control measures at this installation present an early example of curtailing operations to prevent damage or nuisances. In this case, sampling equipment and weather stations provided the data for predicting when the plant should reduce operations to avoid damage over a wide area of farm land.

A number of other processes, too numerous to mention, have been studied and, in some cases, economically employed on sulfur dioxide concentrations above 1% in the stack. Studies are continuing to find new processes for improving existing methods which will be applicable to a large number of industrial processes which have stack concentrations of the above order. However, the largest total tonnage of sulfur dioxide is emitted from the burning of fuels containing sulfur, both by industry and in the homes. In these cases the concentration of sulfur dioxide is far below 1%.

Reduction of sulfur gas emissions from these sources cannot be economically justified today, by any known process. A full scale test installation is under way in England. This process, known as the *Fulham-Simon-Carves* has been under study with the Fuel Research Station and employs a scrubbing of flue gas with concentrated solutions of ammonium salts. Ammonium sulfate and sulfur are produced by adding a small

* Presented at the 50th Annual Meeting of the Air Pollution Control Association, held at St. Louis, Mo., June 2-6, 1957.

amount of sulfuric acid to the scrubbing liquor and heating the mixture under pressure. An earlier effort was made, in 1929 at the Battersea Power Station in London, to solve this problem by scrubbing the gases with water. Tremendous quantities of water are required, obviously dictating a location near an abundant source of water. This experiment resulted in an increased cost of 15% on the coal burned. While there appears to be no widespread demand for the reduction of sulfur dioxide from fuel sources today and inexpensive processes are not available, give is under way will, undoubtedly, give control officials the tools to do the job in the future, if the pressures of concentrating industry continue to build up sulfur dioxide concentrations in the atmosphere.

Dust and Fumes

The interest in recovering valuable materials which were lost in many dust producing operations stimulated the development of electrical precipitation, cyclone collectors, and bag filters. While the value of materials recovered in earth processing industries and smelters seldom represented a large financial return, many industries utilizing the above collectors could economically justify their installation. Most of the engineering studies on this subject were carried on by the industries themselves and, except in the case of the supplying of electrical precipitators, relatively few engineering services or equipment manufacturers were available to industry outside of their own organizations. Also, during this period of development, the pressures to clean up the atmosphere were centered on smoke from coal burning installations. As this effort made headway, demands arose for the collection of fly ash from coal fired power plants. This program greatly enlarged the number of engineering applications for dust collectors and, until very recently, represented the first type of installations, or dust collection, which could not be economically justified.

Since construction of these expensive dust collectors had been geared to paying themselves off in a reasonable time, attempts to apply this equipment strictly to air pollution dust and metallurgical fume problems did not meet with any amount of success until the stringent requirements in Los Angeles for the control of dusts and fumes were established.

When this occurred in 1949, it became necessary for industry to take the techniques established for economic recovery and apply them to processes, regardless of the pay off. After considerable experimentation with cyclonic collectors, wet scrubbers, bag filters, and electrical precipitators, it was found that virtually all dust producing processes and metallurgical processes could control their stack effluents above 85% efficiency in terms of weight.

A large number of stack analyses on all processes were conducted to determine a rough distribution of the particle sizes emitted to the atmosphere. Because of the nature of the Los Angeles smog problem, it was essential to institute controls which would reduce the emission of particles below 5 μ in diam. Most of the metallurgical processes were found to have a large percentago of their stack dscharges in the smaller particle size ranges. Dust producing activities, on the other hand, generally emit a preponderance of larger particles. As each category of industry studied its problem and recognized the need for stringent requirements, suitable equipment was installed. It was indeed fortunate that the early work done with various types of collectors could be usefully employed to meet this new stringent requirement. Numerous examples exist today where metallurgical fume on open hearth furnaces, electrical furnaces, gray iron foundries, and non-ferrous foundries are collecting well above 85% of their total discharge with properly engineered bag filters or precipitators and, in so doing, remove a high percentage of the number of particles below 5 μ. In the cement industry and other earth processing industries cyclonic collectors and wet scrubbers of a variety of types are successfully operated to recover the larger sized materials inherent in these operations.

In connection with establishing the legal justification for correcting problems of this type for the air pollution necessity, rather than for economic reasons, it is interesting to note that, in the early part of this century, public indignation in areas near cement plants resulted in legal actions and court decisions which established firmly the right of government to regulate air contaminants of this type. A test of this right was made when a stringent dust and fume regulation was applied in Los Angeles. The ability of industry and equipment manufacturers to do this job was well illustrated in Los Angeles by virtue of the fact that industry found that the high requirements for dust and fume collection could be met. While it may be argued that the capital investment for the equipment was high, in terms of the benefit, investments for the equipment and subsequent maintenance cost have not affected the competitive position of companies in the Los Angeles area, or prevented industry from establishing new facilities because of these high costs.

At the present time a number of companies in the United States are building, or planning to install, high efficiency collectors for metallurgical fumes. In several industries where new plants are being established, collection devices become an integral part of the new plant. The following tables classify the various types of collectors in relation to the processes and their emissions. They also show the great number of systems to be considered and some of the advantages and disadvantages of each collector. To a large extent, most of these installations are custom engineered and built on the site. The costs cover a broad range.

All of these factors indicate need for thorough engineering studies and fixing of the responsibility for doing a satisfactory air pollution control job in the high echelons of management in industry.

Fluorides

Aluminum plants, phosphate fertilizer plants, and a number of other operations emit small amounts of fluorine compounds to the atmosphere. Without attempting to enumerate the several serious incidents which have occurred, it is well known that following the establishment of several plants in certain areas, many law suits for damage to cattle and forage were brought against the offending companies.

Extensive research revealed the fact that cattle fed on forage subjected to fluoride contamination are seriously affected. As is the case in the field of sulfur dioxide emissions, the companies involved spent large sums studying causes and effects on animals. It was found that vegetation can accumulate fluorides in various forms in the leaves and roots. When this accumulation is passed to the animal a similar build-up results in the system. The normal processes in the plant and animal neither expel the material, nor build up suffi-

cient resistance to overcome tissue damage in plants or animals.

Extensive studies are still continuing in this field today. Engineering applications to remove fluorides are relatively new and have been made by the aluminum industry and others closely concerned with this problem. Hydrogen fluoride is the most common form found in the emission and, due to its affinity for water, it can be removed by scrubbing processes. Fluorides may exist in both the particulate phase and in the gas phase. In stacks where a high degree of elimination is required, the control equipment requires 2 different engineering processes for the 2 forms of fluorides. Several processes have been used in recent years to combat this growing problem. These include water spray towers, absorption in sodium hydroxide, and the use of limestone or other compounds in porous beds.

A serious complication in this entire field is the matter of evaluating the result. Chemical measurements are difficult to perform and, since vegetation is capable of accumulating the fluorides from the air and from the soil, even small emissions may be accumulated to the point of causing damage. In spite of the lack of standardization of chemical techniques, valuable information can be obtained around centers of fluorine production by continuous studies of the fluorine in the vegetation. This approach, perhaps, offers the safest means for evaluating the proficiency of the control equipment.

Hydrocarbons

Our present generation has observed the great increase in the use of petroleum products and the benefits to mankind which have resulted from the mass use of automobiles, buses and trucks. While our attention was focused on our great and expanding economy, on two major wars and a serious depression, the wide-spread use of gasoline was gradually building an air pollution problem which first came to the attention of scientists and engineers interested in this field as a result of the Los Angeles smog problem. In 1951, the author reported to the Air Pollution Control Association the findings in Los Angeles, which pointed out for the first time that gasoline vapors are

TABLE I

Collection Equipment — Solid and Liquid Aerosols.

Type	Dust characteristics: Type	Particle size, μ	Sp. gr.	Pressure drop, in. H_2O	Advantages	Disadvantages	% Efficiency (wt. basis)	Initial cost $/c.f.m.
Centrifugal Collectors								
Simple cyclone	Wood dust	50-1,000	0.4-0.7	0.5-2.0	Simple in construction	Low efficiency	70-90	0.55-0.90
	Grain dust	10-200	0.9-1.1				60-80	
	Mineral dust	10-500	2.0-3.0				70-90	
	Pulverized chemicals	10-500	1.5-3.0				70-90	
High-efficiency cyclone	Catalyst dust	2-80	1.5-3.5	2.0-6.0	Relatively high efficiency	Subject to abrasion damage	65-80	
	Fly ash	0.1-100	0.4-1.5				50-70	0.75-1.10
	Other fine dust	5-200	1.0-3.0				85-98	
Impeller	Foundry dust	10-300	2.5-4.0	Acts as own fan	Low space requirement	Impeller abrasion causing unbalance	70-90	0.75-1.10
Electrostatic Precipitators								
Single-stage	Gray iron Cupola fume	0.5-50	3-6	0.25-0.5	High efficiency under severe conditions	High initial cost, operating difficulties	90-97	1.50-5.00
	Electric steel Furnace fume	0.1-20	5-7				90-97	
	Open hearth steel* Furnace fume	0.1-3	5-7				96-99	
	Catalyst dust	2-80	1.5-3.5				85-98	
Two-stage	Oil mist	10-400	~1	0.25-0.5	High efficiency for low dust loading, safe in operation	Limited in use	85-99	0.90-1.50
	Air conditioning	0.2-10	—	—			95-99	
Cloth Filters								
Tubular	Metallurgical fume			0.5-6.0	High efficiency over wide particle size range	Caking from moisture		0.80-2.50
	Nonferrous	0.03-1.0	~5				98-99.5	
	Ferrous	0.10-50.0	3-6				97-99.5	
Screen or frame	Ceramic dusts	1-50	1-3	0.5-4.0	Somewhat self-cleaning	Higher stresses on filter mediums	95-99.0	0.80-2.50
	Metallurgical fume	0.1-50	3-6				94-97	
Reverse flow (standard cloths)	Same as screen type shown above			0.5-3.0	Higher dust loadings possible	—	—	1.00-2.50
						—	—	
Reverse jet (felt mediums)	Carbon black	0.1-10	1.5	1.0-6.0	High filter ratios possible	Bag wear	99.5	1.00-2.00
	Flour dust	5-100	0.9				99.9	
Wet Collectors								
Spray chamber	Rock dust	40-500	2-3	0.5-1.0	Low pressure drop	High nozzle pressure required for good collection	60-75	0.35-1.50
	Asphalt mist	10-400	~1				70-80	
	Acid mist	20-500	1.1-1.3				70-90	
Inertial	Al and Mg Grinding dust	50-1,000	1.7-2.8	2.0-4.0	No nozzle maintenance	Higher pressure drop	80-95	0.50-1.50
	Foundry dust	10-300	2.5-4.0				70-90	
Centrifugal spray	Rock and sand Dust	20-500	2-3	1.0-4.0	Combined scrubbing and centrifugal action	Abrasion	75-95	0.50-1.50
	Acid and caustic mist	20-500	1.1-1.3				75-95	
Venturi Scrubber	Sulfuric acid Mist from concentrator	2-10	~1.5	10.0-15.0	High efficiency, low water rate	High power consumption	85-95	1.50-5.00
	Chemical fume	0.1-50	1.5-3.5				60-85	

*Cold metal furnaces.

potential air pollutants. The work done in 1950 and 1951, together with the subsequent reports, clearly demonstrated that certain types of hydrocarbons were capable of oxidizing in the atmosphere to produce a variety of effects. Under some conditions, the photo-chemical reaction which takes place between readily oxidized hydrocarbons and oxides of nitrogen in sunlight will produce an eye irritation, a typical type of damage to leafy vegetables, create haze and form ozone. By 1953 the sources of hydrocarbons in the Los Angeles area had been reported, including the amount of hydrocarbons from vehicular traffic. The final conclusive reports, showing the distribution of gases in the Los Angeles atmosphere, clearly showed the role played by traffic in producing a localized concentration of hydrocarbons when adverse weather conditions prevailed simultaneously with the traffic peak. The conclusion that auto exhaust must be controlled in Los Angeles was inescapable.

For several years a parallel interest has been expressed on the subject of automobile exhausts in Paris and London. Air pollution control officials in several U. S. cities have reported occasional incidents of eye irritation under unusual weather conditions. Also public complaints against the odors from buses and diesel trucks appeared in the newspapers of many cities.

Other types of hydrocarbons may be found in rendering plants, chemical plants, enamelling ovens, and a variety of other operations. The accompanying table shows the various types of control processes which may be applied for collection or destruction of organic vapors. Vapor recovery or adsorption systems are usually employed where the quantities of materials recovered are sufficient to pay for the control equipment. Incineration or combustion with oxidation catalysts methods are used where the quantities are small but represent important pollution sources.

Some authors include in the hydrocarbon category all types of odors and, in some cases, effluents from rubbish burning incinerators. A number of approaches are available for the control of odors, including incineration, oxidation catalysts, and absorption. The reduction of the contaminants from incineration is best accomplished by appropriate design of the equipment, which fundamentally includes proper distribution of air, reduction of burning rate and, perhaps, a water scrubbing system for the elimination of the larger particles. The many details that are involved in the elimination of odors and the design of the incinerators cannot be included in this paper. Many groups are continuing to study the basic factors which will improve the design of incinerators. The introduction of oxidation catalysts, which are capable of burning diluted concentrations of organic vapors without flame, has been an important new contribution to the engineering field in the past few years. Because of the difficulty of obtaining identification and quantitative measurements, the problem of eliminating odors continues to represent the most difficult field in the control of contaminants.

Engineering Principles

Perhaps the greatest amount of progress has been made in applying many of the basic sciences to the air pollution field, in order to develop a better understanding for applying

TABLE II

Classification of Control Devices for Gases and Vapors.

Control method	Contaminants	Sources	Remarks
Absorbers (scrubbers)			
Packed towers	Malodors	Rendering plants, chemical plants, etc.	Absorption solution: oxidizing agents.
Plate towers	Hydrocarbons	Oil refineries	Absorption solution: absorption oil. (Oil is stripped and recirculated.)
Spray towers Spray chambers Water jets	Acid Gases H_2S	Thermal and catalytic cracking plants	Absorption solution: ethanolamines, potassium phosphate, Thylox, sodium phenolate, etc. (The solutions are regenerated.)
	SO_2	Flue gases, chemical plants	Absorption solution: $NaOH$, $(NH_4)_2SO_3$-NH_4HSO_3, water, alkaline solution. (Chemicals must be replenished.) Dimethylamine (regenerated).
	HNO_3	Chemical plants	Absorption solution: alkaline solution.
Incineration			
Flares	Hydrocarbons	Oil fields, refineries	Venturi burners or steam injection required for smokeless combustion.
Fume burners	H_2S	Oil refineries, chemical plants	SO_2 is product of combustion.
	Malodors	Rendering plants, refineries, chemical plants, paint manufacturing, food processing, etc.	Temperature required 900-1200°F.
Catalytic combustion	Organic vapors	Litho and enameling ovens, rubber compounding, plastics, etc.	Catalysts: platinum, nickel. Temperature required 500°F.
	CO, oil vapors, NH_3	Catalytic cracking unit regenerators	
Adsorption	Organic solvents	As above	Mediums: activated charcoal, silica gel, activated alumina. Mediums regenerated by heat and stripping; disposal of liberated odors, etc., by incineration or other means.
	Malodors	As above	
Vapor recovery systems	Gasoline, crude oil, and other volatiles	Storage tanks	Vapors may be compressed and liquefied or may be burned as fuel or flared.
Floating roofs*	Gasoline, crude oil, and other volatiles	Storage tanks	

*A floating roof is a cover on a vertical cylindrical type of tank which rests on the surface of the liquid within the tank and moves as the level of the liquid changes.

control measures. Over the past 50 years, many scientists have contributed their individual studies on sampling procedures, measurement techniques, instrumentation, analysis of stacks, and the influences of meteorology. These techniques have been accepted and applied to air pollution problems in this country and abroad. While the field has not reached the degree of standardization that is experienced in the older engineering fields, it is now possible to define the air pollution problems for a given plant or for a community.

This definition begins with a complete understanding of the topography and meteorology in relation to either the single plant problem or the community problem of air pollution. Following this study, analysis of the source, or sources, to define the physical properties, or chemical properties, of the contaminants is necessary.

Once the nature of the problem is determined and the sources and weather facts are evaluated, control measures can then be devised to relieve the detrimental effects resulting from atmospheric pollution. Where prolonged inversion conditions create a community problem, the effects can be minimized only by a control program against all air contaminants. Single sources may be treated to relieve local nuisance conditions. Regardless of the degree of control measures required, three basic methods can be applied to reduce the various contaminants which may be conviently classified as aerosols, vapors and specific gaseous contaminants.

(1) Reduction at the source is accomplished by the installation of collection equipment, improving the design of basic equipment, or through operational changes which inhibit the discharge to the atmosphere.

(2) Dilution of the source is accomplished by using sufficient air to make the discharge unobjectionable. Tall stacks illustrate one means of applying this principle.

(3) Allocating the use of the land to prevent harmful concentrations from occurring at a single source, or from an area having many sources, can be an effective measure. In applying this principle, the mass rate of emission from an area is prorated over the acreage utilized by the sources. Either the acreage to be occupied, or the total contaminants discharged can be regulated to avoid harmful concentrations. The mass discharge will be governed by the total activity in a given area.

In applying any one of these three approaches, the engineer must consider the question of degree of improvement to the air, or the efficiency of control equipment. It is unfortunate that so little progress has been made to provide standards which will assist in this determination. If the economic factors alone are considered, the control official, or engineer, will decide in favor of the least expensive and, usually, lowest efficiency equipment. All too frequently, a *trial and error* approach is used which, at best, is time consuming and costly. If the decision is based upon the premise that *the community cannot afford the luxuries of half-way measures,* then the best known engineering process will be required. The fact that specified limits for stack discharges, or for allowable levels in the atmosphere, cannot be standardized at this time, leaves the matter to the judgement and the experience of the parties involved to come up with the control measures which will satisfy the public complaints. At the present time there is no immediate solution in sight for this problem, yet the efforts and experience of this association can be utilized to establish criteria for proper solutions and can do a great deal to avoid the promulgation of standards which are too often hastily considered.

Health Research

In the event that health studies on air contaminants should conclude that any category of air pollutants in the general atmosphere affected health, the matter of setting limitations would be rapidly concluded. A final determination of acute effects, or chronic effects of air pollutants, by health authorities, would undoubtedly result in very precise standards, such as are found today for the protection of workers indoors.

This whole subject is indeed controversial at this time. Any survey on the literature over the past 50 years clearly indicates a divided set of opinions between medical authorities on the potential effects of air contaminants on the general public. For the most part, all such conclusions were pure opinion and not based upon complete clinical or epidemiological studies. The past 10 years have seen a decided acceleration of research in the laboratory and in the field. The products resulting from partially oxidized gasoline vapors have been shown to produce cancers on the skin and in the lungs of animals when exposed to concentrations near those found in the atmosphere in some areas. The effects of ozone are being studied by several investigators, and increased emphasis is being placed upon dust and fumes in the sub μ particle size ranges. Now that techniques are available for identifying the air contaminants, it can be expected that this work will proceed with much more accuracy and more emphasis than was shown in the past.

Because of the dramatic incidents of serious effects of air contaminants in London and Donora, the public fear of *the unknown* has been stimulated. Governmental health authorities have been pressed to answer the question on effects to the public. The growing concern as to the possibilities of explaining the great increase in lung cancer as a result of our increase in air contaminants has been marked during 1956. Many people have already made up their minds that air pollution affects their health. Air pollution officials cannot afford to ignore these pressures on the health aspects of the air pollution problem. Until such time as complete proof is available, and standards have been developed, the safe approach is to control to the maximum of our engineering knowledge. New industrial processes should be carefully analyzed and studied for control measures. Internal combustion engine exhausts, which contribute such large tonnages to the general atmosphere of our cities must ultimately be controlled. Studies should be continued to find solutions for the reduction of sulfur dioxide in power plants and refineries.

As in all matters of engineering, economic consideration must be given to the relative costs of the different control processes, but the protection of a valuable resource, such as our atmosphere, can best be safe-guarded by the control official who considers that *he cannot afford the luxury of half-way measures.*

In conclusion, it is well to consider two statements made in the past year. The *Cancer Research Journal* carried an article which concluded with this statement: *A review of the factors relating atmospheric pollution to lung cancer both on the epidemiological and experimental level, warrants its incrimination as one of the dominant agents etiologically associated with the increase in mortality from lung cancer now being reported in various*

regions of the world.[1] Recently a world famous scientist, in reviewing this subject before a group of doctors, made the following statement:

From 1775 until 1957, but particularly during the last 50 years, industrial research and medical research jointly, by chemical analysis and practical application on animal and plant life, has led an array of brilliant scientists to the conclusion that hydrocarbons are mainly responsible for cancer increase.

Those hydrocarbons come from industrial plants and daily human activities such as operation of automobiles, Diesel buses, incinerators and household burners, with the result that we live in an atmosphere supplied continuously with carcinogenic agents. Those dreadful products enter our lungs and our stomachs, for they settle on food in shops and vegetables in the fields.[2]

These conclusions, together with the daily evidence of the control officer, seems to speak clearly for maximum controls on all forms of pollution for which solutions are known, and clearly indicates the need to develop control measures for emissions of hydrocarbons from industry and motor vehicles. This Association and the control officer in the field have the prime responsibility for insuring that the application of engineering principles is soundly applied to all sources which will protect the public from any nuisance or hazard, and that the necessary legal tools are obtained to accomplish this objective in each community.

(1) Dr. Paul Kotin

(2) Eugene J. Houdry

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A Review and Appraisal of Air Pollution Legislation in the United States*

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Historically, the anti-smoke regulations of England, drawn up in the 14th Century, might be considered the earliest recorded legislation dealing with an air pollution problem. During the latter half of the 19th Century the problem of smoke in many American and European cities was sufficiently serious to result in the establishment of various smoke commissions to inquire into the causes and prevention of smoke.

Although there had been private litigation with regard to smoke in St. Louis as early as 1864, the first ordinance in this country, giving specific authority to a local government to regulate it, was adopted by Chicago in April 1881. Cincinnati adopted a smoke ordinance in November 1881 and St. Louis in 1893. By 1912, 23 of 28 cities with more than 200,000 population had smoke abatement programs.

The great impetus in the enactment of air pollution control legislation occurred shortly prior to and following World War II. Comprehensive control of air contaminants is a fairly recent development and over 80% of all present municipal air pollution abatement ordinances reviewed have been enacted in the last 15 years (Table I). It becomes readily apparent that such legislation occurred as a result of a tremendous industrial growth along with a rapid population growth of our larger cities. The reaction to the problem of air pollution in many areas was the enactment of control legislation. Unfortunately, however, many of our laws on the subject of air pollution are antiquated and lack adequate factual substantiation. This occurred in spite of the research that was undertaken during the early decades of this century. It appears, therefore, that a considerable lag period ensued between the completion of the studies and the acceptance and application of the results by communities. In this connection, the need for determination of basic criteria of air cleanliness in the community atmosphere still exists. Such criteria, whenever possible, should best be based on definite scientific data and considered in relation to the significance of all the pollutants present. Obviously, in those areas where significant air pollution problems exist, interim control activities, based on the best information available, should be inaugurated.

* Presented at the 50th Annual Meeting of the Air Pollution Control Association held at St. Louis, Mo., June 2-6, 1957.

Legislative Material Reviewed

The legislative materials utilized for this review were obtained in response to a questionnaire distributed in the early part of 1956 by the Air Pollution Control Association in connection with the preparation of a *Directory of Smoke and Air Pollution Control Agencies*. The air pollution legislation of 110 cities forms the basis of this review. In addition, certain aspects of air pollution legislation in seven States is briefly presented. However, before the findings are presented in detail, it is desirable at this point to consider certain legal aspects which provide the basis of much of the legislation enacted thus far.

Legal Aspects of Air Pollution Control

The governmental structure of the United States is based on the Constitution. In this durable document, the States are established as the primary entities for the enactment of legislation governing the activities of our citizens. The role of the Federal Government is set forth generally as one of providing for those matters most properly treated by a single agency as the representative of the several States. The Tenth Amendment, a part of the Bill of Rights, adopted in 1791, 4 years after the ratification of the Constitution, specifically reserves for the States or the people the right to exercise all powers not delegated to the Federal Government.

States, under the powers reserved for them as previously mentioned, may undertake to provide for the control of air pollution through the use of the common law relating to nuisances (common law being a code of practice resulting from court decisions and custom). Such actions are cumbersome and, in addition, there is no course of action available to the enforcement official to require the control of the situation by employment of suitable engineering techniques, especially upon initial construction.

States also may be construed to have the power to declare certain acts or situations to be nuisances which are not such at common law. To declare air pollution or the emission of pollutants into the atmosphere to be a nuisance simplifies the control ac-

TABLE I
110 Cities With Air Pollution Ordinances By
*Year Of Present Ordinance Adoption

Population group	1911-1920	1921-1930	1931-1940	1941-1950	1951-1956
Under 50,000	1	2	3	7	13
50,000-99,000	1	3	3	8	9
100,000-199,000		1		7	9
200,000-499,000				7	6
500,000-999,000			3	4	2
1,000,000 & over			1	3	3

*Note: The date used is that of the most recent ordinance adoption.

TABLE II

Administrative Air Pollution Agency

In 110 Cities Having An Air Pollution Ordinance

Population group	Health	Dept. of Public Safety	Building Dept.	Dept. of Public Works	Dept. of A.P. Control	A.P. Control District	Other	None	Total
Under 50,000	2	6	4	4	2	—	6	8	32
50,000-99,000	2	2	3	3	3	2	4	7	26
100,000-199,000	2	4	—	3	4	—	4	2	19
200,000-499,000	1	6	3	2	—	1	2	1	16
500,000-999,000	2½	2	1	½	2	1	1	—	10
1,000,00 & Over	1	—	1	—	1	3	1	—	7
% of Total	10	18	11	11	11	6	16	16	

tion just described by eliminating the necessity of proving the existence of a nuisance in each case.

The police power available to States merits serious consideration as the basis for a control program. Under these powers, laws may be enacted to provide for the regulation of human behavior, the conduct of business, the use of property, and so on, with reference to the maintenance of public order, and the protection of the public health, safety, morals, and order. Under these very broad, but not unlimited powers, a program can be provided which will effectively bring about control of air pollution. Reasonable requirements can be established regulating emission of pollutants, use of equipment, processes and materials, plan approval and permit systems, and other facets of a suitable air pollution ordinance. Such a law need not be based on past findings, court decisions, or custom, but can be originally established in accordance with the desires of the public expressed through their official representatives and maintained by suitable amendments to the law or by revision of rules and regulations, if such are provided for.

There are 2 general legal approaches to air pollution control by local communities; *i.e.*, public nuisance and specific legislation. In the absence of specific legislation, control of a source of pollution can be effected in practically every jurisdiction in the United States by proving to the satisfaction of the court that it creates a public nuisance. Air pollution *per se* is not considered a common law nuisance unless it is proved to interfere materially with the enjoyment of life and property.

Nuisances are further classified as first, nuisances *per se*, *i.e.*, those acts which have been so designated by common law or statute; second, acts which in their nature are not nuisances but may become so by reason of their locality, surroundings, or manner in which they may be conducted; and third, those which in their nature *may* be nuisances but as to which there may be honest difference of opinion in impartial minds. However, no activity which cannot be shown to be a nuisance in fact, may rightfully be declared to be a nuisance *per se* by a legislative body, nor may a State or municipality authorize by law an act which can be shown to be a nuisance.

Findings

The legislation under study revealed a multiplicity of local governmental agencies responsible for the administration of air pollution control legislation (Table II). Although 6 agencies are indicated as the principal ones, we find that there were 18 communities which utilized other local agencies, and 18 communities did not designate any specific agency in their ordinance. Of the ordinances reviewed, approximately 40% designate their Department of Public Safety, Building Department, or Health Department as the enforcement agency. Other departments following closely in frequency of designation are the Departments of Public Works and specifically created Departments of Air Pollution Control. It appears that the choice has almost always been to seek an existing municipal agency and add air pollution control to its other duties.

A solution becoming more frequently utilized is the establishment of an Air Pollution Control District. This procedure has been successful in areas involving large or small communities and varying proportionate combinations. It offers a number of distinct advantages which may be listed as follows:

(1) Full-time air pollution control program.

(2) Per capita cost/square mile of coverage is less.

(3) Control of community air pollution sources from beyond community boundaries.

(4) Community awareness and interest.

Properly drafted legislation will delineate the scope of responsibility of the administrative agency and, in turn, such responsibility determines the type of agency most suitable to carry out the program of air pollution control. To carry this consideration one step further, we must recognize that in the drafting of legislation there is usually a balancing of equities which may affect the scope of administrative control activities.

Enforcement Agent

Many of the ordinances reviewed specifically indicate the official responsible to the administrative agency for enforcement of air pollution control legislation (Table III). In certain instances, the legislation indicates the bureau or agency responsible for enforcement rather than indicating a specific official. The air pollution control legislation reviewed indicates that approximately 14% specified an enforcement officer other than one of those listed on Table III and that at least 11% made no specific provision as to who the enforcement officer would be. The enforcement officers appearing most frequently in the legislation were *(a)* Air Pollution Control Engineer (17%); *(b)* Bureau of Air Pollution Control (13%); and *(c)* The Commissioner of the Department acting as the administrator of the program (9%).

Duties of the Air Pollution Control Officer

Sound administrative practice dictates that the duties of the Air Pollution Control Officer be specified for purposes of clarity in the ordinances

TABLE III

Enforcement Officer Designation
In 110 Cities Having An Air Pollution Ordinance

Population group	A.P. Control Engineer	Health Officer	Smoke Abatement Insp.	Bureau of A.P. Control	Department Commissioner	Building Inspector	Other	None
Under 50,000	2	2	7	2	2	3	8	6
50,000-99,000	5	2	5	1	1	3	4	5
100,000-199,000	4	1	—	5	2	2	4	1
200,000-499,000	5	1	3	2	2	2	1	—
500,000-999,000	1	1½	3½	3	—	—	1	—
1,000,000 & over	2	1	—	1	3	—	—	—
% of Total	17	8	16	13	9	9	16	11

of the respective communities. It will be observed that regardless of community size with respect to population generally the principal duties of the Air Pollution Control Officer are as follows:

a. The investigation of complaints and the investigation and observation of air pollution conditions.

b. The examination of plans and specifications for new construction and reconstruction or alteration of fuel-burning equipment and issuance of installation permits.

c. Inspection of new installations and issuance of operating permit or certificate.

d. Enforcement of provisions of the ordinance, orders, rules, and regulations.

Other duties may be the dissemination of information to the public, inspection of existing installations, conduct of research, technical assistance, and the development of rules and regulations. In general, the duties are those related to abatement and prevention of air pollution problems. It is significant to note, however, that although it may be implied, there is rarely any specific mention of the need for development of a broad program to secure compliance with the ordinance provision concerned.

Definitions

Our review reveals that 78% of all air pollution control ordinances under study contain a section dealing with the definition of specific terms (Table IV). It is significant to note that although communities of over a half million always provide for a section on definitions, many of the smaller communities fail to do so. In the group of communities of less than 50,000 population, only 53% of the ordinances contain a section of definitions.

The inclusion of suitable definitions is of major importance to the successful implementation of an ordinance. Failure to do so results many times in dispute as to intent and scope of the ordinance provision requiring both legal and administrative interpretation. It is most desirable that the ordinance be prepared in the clearest terms possible so that intent is apparent and not subject to misinterpretation.

Boards—(Advisory, Appeal, Hearing, etc.)

The extensive utilization of advisory and appeal boards in addition to affording a device for the holding of hearings by the administrative or enforcement officer reflects the level of development of knowledge concerning air pollution control and the consequent broadening of the base of administrative responsibility. Concerted efforts to control air pollution are of relatively recent origin and there has been no extensive backlog of data upon which to make objective determinations. In those areas where measurements of one type or another are made, they must be interpreted along with other factors which are not adequately measured and are at times subjectively determined. This has led to the practice of using boards which may advise the control officials as to program and enforcement actions and other boards which hear appeals on actions of enforcement officials. Certainly the use of boards is a safety device to assure a reasonable and nonarbitrary approach to air pollution control. In some communities the advisory and appeal functions are incorporated in one and the same board. Most communities which use an advisory board also delegate to that board the responsibility of approving the rules and regulations developed by the Air Pollution Control Officer. Of the 32 communities having less than 50,000 population, whose ordinances were reviewed, only 31% provided for a board of any type; however, in the larger population groups greater use is made of various board (Table V). Usually all the more elaborate programs provide for appeal to a hearing board. Generally the agency with the right to summon witnesses and put them under oath must guarantee rights of counsel and give a 10-day notice of hearing. Some programs also allow the appeal board wide discretion in granting variances from the air pollution regulations, especially when the consequences of not granting the variance may prove disastrous to the industry in question or affect the community's economic stability.

TABLE IV

Definitions In Air Pollution Ordinances Of 110 Cities

Population group	Provided	% of group providing	None
Under 50,000	17	53	15
50,000-99,000	20	77	6
100,000-199,000	17	89	2
200,000-499,000	15	94	1
500,00-999,000	10	100	0
1,000,000 & Over	7	100	0

Approximately 78% of the ordinances reviewed provided a section defining certain terms used in the ordinance.

Smoke Emission Prohibitions

Most air pollution control ordinances describe dense smoke and de-

TABLE V

Provision For Boards

In Air Pollution Ordinances Of 110 Cities

Population group	APC — boards				Special boards					Other	None	% of group
	a	b	c	ab	a	b	c	ab	abc			
Under 50,000		1			2	3	2	1		1	22	31
50,000-99,000	1	2½	½		1	6			3	1	11	58
100,000-199,000	⅓		⅓	2½	1	5⅓	½	2	1	2	4	79
200,000-499,000				1	2	3	1	1	1		7	56
500,000-999,000		1½	½			2		2	1	1	2	80
1,000,000 & Over		½	2⅓		⅚	⅚	½		1		1	86
Totals	1⅓	5½	3⅔	3½	6⅚	20⅙	4	6	7	5	47	

Approximately 53% of the communities provide one or more boards in accordance with ordinance requirements.

Note: a — Advisory
b — Appeal
c — Rules & Regulations

c are such smoke a nuisance. It is a ɔparent from Table VI that the most c ɔmmonly accepted standard for de- t rmining the density of smoke emis- s ons is the Ringelmann Chart. In s ɔme communities it is permissible t ɔ use any other chart or standard h aving equivalent shades of grey, v hen viewed at the intended viewing c istance for each. Other instruments c r devices permitted are the micro-Ringelmann Chart, the Smoke Scope, a nd Umbrascope.

Smoke emission density limits most c ommonly employed are of 2 types:

a. Those ordinances which prohibit emissions equal to or greater than No. 2 of the Ringelmann Chart except for limited periods for fire cleaning or building when no specific limit is established. This provision occurred in approximately 46% of the ordinances (Table VI).

b. Those ordinances which permit No. 2 smoke at all times and in excess of No. 3 for limited periods during fire clean- or building. This provision appeared in 22% of the ordinances reviewed (Table VI).

Although not presently included in a large number of ordinances, much new impetus has developed which would include a prohibition of smokes other than black or grey. It would prohibit emission of air contaminants of such opacity as to obscure an observer's view to a degree equal to or greater than the smoke prohibited by the use of the Ringelmann Chart.

A rather recent innovation involves the use of a table of permissible smoke emissions on the basis of the type and size of source and location. This procedure offers a rational approach to the problem of smoke emissions and its effectiveness may be enhanced when employed in conjunction with suitable zoning regulations.

Particulate Matter Emission Prohibitions

A study of Table VII reveals a rather wide variety of dust emission prohibitions principally resulting from various processes of combustion. There are two limits of emission which account for 50% of those communities having an ordinance provision dealing with this item. These provisions are:

a. Dust or fly ash emission limitations of not in excess of 0.85 lb./1,000 lb. of stack

TABLE VI

Smoke Standards Classification

Of 110 Cities Having Air Pollution Ordinances

Population group	II		III		V	VI	VII	VIII	None
	A	B	B	C	B				
Under 50,000	2	8		9		1	2	4	6
50,000-99,000	1	14	2	6	1	1	1		
100,000-199,000	1	11	1	4				1	1
200,000-499,000	2	10		4					
500,000-999,000	1	5	1	1		1			1
1,000,000 & Over	3	3	1						

Approximately 93% of the ordinances reviewed provided for a smoke emission density limitation.

Footnote: (Table VI)
Definition of Ordinance Classifications
Based on the Measurement of Smoke Density

Class II: Ordinances which allow short periods of No. 2 smoke:
A. But may not exceed No. 3 for stated periods for fire cleaning or building.
B. And may exceed No. 3 for stated periods for fire cleaning or building.

Class III: Ordinances which allow No. 3 smoke at al ltimes:
A. But may not exceed No. 2 at any time.
B. But may not exceed No. 3 for fire cleaning or building.
C. And may exceed No. 3 for fire cleaning or building.

Class V: Ordinances which allow No. 3 smoke at all times:
A. But may not exceed No. 3 at any time.
B. And allow periods in excess of No. 3 without specifying or in addition to fire cleaning or building.
C. And may exceed No. 3 for fire cleaning or building.

Class VI: Ordinances which define smoke density using the Umbrascope and not in terms of the Ringelmann Chart.

Class VII: Ordinances which do not, or only loosely, define the smoke density prohibited.

Class VIII: Table establishes limits on basis of type and size of installation.

Ringelmann Chart. This is the most widely used method and was sponsored by the U. S. Bureau of Mines. The smoke density is expressed on a scale of 0, 1, 2, 3, 4, and 5. No. 1 smoke allows 80% of the transmitted light to pass through, No. 2 allows 60%, No. 3 allows 40%, No. 4 allows 20%, and No. 5 allows none of the transmitted light to pass through.

TABLE VII

Particulate Matter—(Standards)

Of 110 Cities Having Air Pollution Ordinances

Population group	1	2	3	4	5	6	7	8	9	Other	None
Under 50,000			3	1	1			3	1	3	20
50,000-99,000	1	1	2					1		2	21
100,000-199,000	1	1	3	1	1	3				1	10
200,000-499,000			2	1		1	1	6		0	5
500,000-999,000	1	1	1			1		2	1	2	3
1,000,000 & Over	2	2	1				1	1		2	1

FOOTNOTE: (TABLE VII)

Column 1 — 0.4 gr./ft.^{3} of gas calculated to 12% CO_2 — combustion.
Column 2 — Process weight table for other than combustion.
Column 3 — 0.85 lb./1000 lb. of gas — adjusted to 50% excess air.
Column 4 — Not more than 0.2 lb. of dust larger than 44μ/1000 lb. of gas.
Column 5 — 0.35 gr./ft.^{3} at 500°F. — not $>$ 50% excess air.
Column 6 — 0.75 gr./ft.^{3} at 500°F. — not $>$ 0.2 gr./ft.^{3} $>$ 44μ — not $>$ 50% excess air.
Column 7 — 0.30 gr./ft.^{3} at 500°F.
Column 8 — 0.85 lb./1000 lb. — adjusted 12% CO_2.
Column 9 — 0.2 lb./1000 lb. not $>$ 44μ.

Note: Some comunities have specific provision relating to particulate matter from combustion or noncombustion processes.

gases adjusted to 50% excess air (11% Table VII); and

b. Dust emissions not in excess of 0.85 lb./1,000 lb. of stack gases adjusted to 12% carbon dioxide (CO_2) (12% Table VII).

These emission limits attempt to prevent excessive dilution of the stack effluent which would violate the intent of the ordinance. Further examination of the remaining limits or standards indicates a wide variation in the quantity of dusts permitted to be emitted from the stacks. In some cases a provision is contained with regard to size, limiting particulate matter dimensions. Not more than 0.40 lb. of particulate matter/1,000 lb. of gases should be retained on the 325-mesh U. S. standard sieve. In others, there are specific provisions relating to industrial dusts and fumes which limit emisisons on the basis of the weights of material processed.

Review of the ordinances of 32 communities with less than 50,000 population showed 63% did not have any ordinance provision specifically dealing with dust or fly ash. Analysis of ordinance provisions where there is greater industrial activity indicates that the problems of dust emission control have received greater attention. Although approximately 45% of the ordinances reviewed provide for control of dust emission, it is important to recognize that such provisions generally impose responsibility for determination of such emissions. This, in turn, requires the availability of adequately trained personnel.

Other Standards

In addition to specific dust emission limits, the emission of other contaminants is controlled by a general provision relating to an air pollution nuisance and one which prohibits the discharge of such quantities of air contaminants or other material which causes injury, detriment, nuisance or annoyance to any person or the public or which endangers the comfort, repose, health or safety of any person or the public or which causes or has a natural tendency to cause injury or damage to business or property. Although this is a highly inclusive provision, its effectiveness is dependent upon the ability of the enforcement agency to demonstrate that a nuisance did exist. Under conditions which may be transitory in nature, the establishment of existence of a nuisance is difficult. In spite of the handicaps indicated, the inclusion of such provisions is desirable, provided that the local governments have such authority delegated to them by the State constitution, or statutory provisions, or by means of a local charter. This provision was included in 74% of the ordinances reviewed (Table VIII).

It is noted that only 18 out of 110 community ordinances reviewed had a provision establishing maximum limits on solid fuel's volatile content (Table VIII). The range of maximum volatility permissible varies from 20 to 26%, the majority using 23% as the limit.

In connection with the establishment of limitations for specific contaminants other than smoke and dusts, only 3 of the 110 ordinances reviewed restricted the emission of sulfur compounds calculated as sul-

TABLE VIII

Air Pollution Nuisances And Other Standards

Of 110 Cities Having Air Pollution Ordinances

Population group	A.P. nuisance	Fuel — (% volatility)					SO_2
		20	21	23	24	26	
Under 50,000	22	1		2			
50,000-99,000	16	2	1				1
100,000-199,000	13			2			1
200,000-499,000	14	1		1		1	
500,000-999,000	10	1		3		1	
1,000,000 & Over	6			1	1		1
Total	81			18			3
% of Ordinance Reviewed	74%			16%			3%

TABLE IX

Permits And Fees Required
In 110 Cities Having Air Pollution Ordinances

Population group	Plans & specs	Installation	Operation	Fees
Under 50,000	14	14	11	12
50,000-99,000	12	12	10	10
100,000-199,000	11	11	7	10
200,000-499,000	12	12	9	9
500,000-999,000	10	10	10	10
1,000,000 & Over	7	7	6	5
Total	66	66	53	56
% of Ordinances Reviewed	60%	60%	48%	51%

Note: Certificates of Operation, where required, are issued after inspection of installation or alteration, also as a result of annual inspections (23.5%).

fur dioxide in each instance to 0.2% by volume (Table VIII).

Permits and Fees

One of the principal devices for control of air pollution sources, specifically fuel burning, is the requirement of installation permits prior to the construction, installation, or alteration of such equipment. Generally, plans and specifications are required to be submitted for review and approval to the air pollution control agency before a permit is issued. Upon completion of installation and prior to actual use, an operation permit or certificate may be issued. The intent of such provisions is of a preventive nature and, to this extent, has merit. Of course, it also provides a means of registering point sources of possible air pollution. This procedure does place considerable responsibility upon the control authorities, both administratively and technically.

On the basis of the ordinances under review, we find that 65% provide for issuance of an installation permit and 60% require submission of plans and specifications; however, only 48% of the ordinances provide for the issuance of a certificate of operation (Table IX). This certificate is usually issued subsequent to inspection of the installation. Very few of the ordinances contain authorization for suspension or revocation of a permit for cause.

It will be observed that approximately 50% of the ordinances reviewed contained provisions for establishment of a fee schedule (Table IX). The criteria for such schedules are variable; in some instances the fees are based upon furnace volumes; in others, the square ft. of direct radiation are used; or BTU/hr. output; or area of the grate surface; in others, a simple fee assessment method is utilized depending upon the type of consumer involved.

Severability Clause

Only 50% of the communities under consideration had a separability or severability clause included in their ordinances (Table X).

The failure to include a clause dealing with the legality of the ordinance was common in all population groups with a greater preponderance in the smaller groups. The desirability of including a clause of this type is obvious. It prevents the possibility of nullifying the effectiveness of the entire ordinance in the event of court ruling against the administrative agency from an action concerning a section, clause, or sentence of the ordinance.

Variances

The granting of variances is provided for in only 29 of the 110 ordinances reviewed or approximately 26% (Table X). This device permits the granting of a variation from compliance with certain requirements of the ordinance concerned. Normally, the issuance of a variation is dependent upon the weighing of the equities involved and the advantages and disadvantages to the residents of the community and to any lawful business, occupation, or activity involved, resulting from requiring compliance with said requirements or resulting from granting a variance.

Sale of Fuel-Burning Equipment

Some communities utilize a provision in their ordinance which requires the reporting of sales of fuel-burning equipment by the seller. This provision may be in addition to the requirement for installation permits. Generally, such reporting exempts equipment used in private residences. Only 18% of the ordinances reviewed contained such a provision (Table X). The distribution indicates more frequent inclusion of this provision in higher population groups. A provision of this type usually requires additional clerical assistance and the cooperation of persons selling such equipment. The relative value of requiring reporting of sales of fuel-burning equipment is open to considerable debate.

Enabling Authority

It has been reported on the basis of a recent survey that air pollution control agencies were created by certain legal devices as follows:

State Law	17%
Local Charter	8%
Local Ordinance	79%
Board Regulation	2%
Administrative Order	2%
Other	3%

Note: *In some cases more than one device was employed which accounts for the total percentage exceeding 100.*

Further analysis indicates that the local ordinance was the legal device used most frequently for establishment of the basic legal authority for an air pollution control program of the community.

TABLE X

Miscellaneous Ordinance Provisions
In 110 Cities Having Air Pollution Ordinances

Population group	Separability clause		Variance authority		Reporting sale of equipment	
		% Group		% Group		% Group
Under 50,000	11	34	4	13	4	13
50,000-99,000	13	50	9	35	3	12
100,000-199,000	13	68	6	32	3	16
200,000-499,000	9	56	1	6	3	19
500,000-999,000	5	50	5	50	4	40
1,000,000 & Over	4	57	4	57	3	43
Total	55		29		20	
% of Ordinances Reviewed	50%		26%		18%	

In another recent study, it was concluded that approximately 10,000 communities in the United States have local air pollution problems. By breaking down this estimate with respect to population and urbanization and by subtracting from this breakdown a similar one for the number of these communities which already have some form of specific air pollution control legislation, it is found that there are approximately 7,500 jurisdictions in which there is need for some form of legislation. It is further estimated that over 95% of this need lies in communities of less than 25,000 population.

The consideration of legislation for the control of air pollution at all levels of government requires the determination of a need for such legislation. Logically, following such determination, is the drafting of the legislative provisions. In this connection, certain broad guidelines are desirable. A basic criterion for the inclusion of a provision is that it will aid in accomplishing the purpose of the legislation, recognizing the equities involved. It has been the effort of most legislative acts to promote equity for all concerned on the concept that the amounts of air contaminants should be limited so that there will not be *too much*, but permitting the atmosphere to function as a receptor of such materials to the limits of its capacity. The fundamental problem to be resolved is the establishment of reasonable limits which prevent any health, economic, or technical hazards based on an evaluation of the factors affecting air pollution levels of the area concerned.

As indicated earlier, legislation is the effort of a legal entity to meet a problem of significant importance to it. Essentially, it provides a tool, but the successful utilization of this tool is dependent upon competent administration of the control program. A number of the ordinances reviewed failed to provide any administration of the control program, and some of the ordinances reviewed failed to provide any administrative structure.

Police Powers

Most jurisdictions have basic police powers adequate to abate atmospheric nuisances originating within their own boundaries. There is need for legislative indication as to which governmental unit of the jurisdiction is to exercise these powers. Where this responsibility is placed is a matter for determination by local and political considerations. However, it is of paramount importance that such responsibility be placed in such a manner that will permit establishment of a competent staff, both in number and specialized training.

It has become generally recognized that the control of air pollution requires consideration of the problem on an area or basin concept, wherein the air pollution area is unique unto itself. Consequently, the legislation may provide a mechanism to achieve control beyond the limits of the jurisdiction concerned. The methods of achieving such control, dependent upon appropriate enabling legislation, might include the establishment of district-wide control involving one or more jurisdictions. It should be emphasized that whatever legislative approach is adopted, it should be based on the magnitude of the problem, both in terms of the area involved and the levels of air contaminants present. It is obvious that acceptance of the *concept of uniqueness*, in turn, requires that legislation should be specifically adapted to meet the problems of the jurisdiction or area rather than the adoption of so-called model ordinances.

State Legislation

Although organized State air pollution control activities have not been common, there has been an increasing interest in such programs in recent years. This interest has been accompanied, or perhaps has been generated, by acute episodes of air pollution which have caused human death and illness, by increasing incidence of irritative effects, nuisance and damage to agriculture and structures, and by increasing cognizance of the complexity of the technical problems involved in the control of air pollution. There has been increasing demand for action at the State level to supplement the recognized local legal responsibilities for air pollution control. In fact, in a great majority of the States, more and more effort is being made to assist local governments in the solution of their air pollution problems even where specific authorizing legislation or funds specifically appropriated for this purpose are lacking.

Of the several laws specifically authorizing comprehensive State air pollution control programs, all except one have been enacted since 1954. There is considerable variability among these enactments. There has been relatively little operating experience with these laws, and the circumstances vary in the several States involved.

In Oregon, New Jersey, and New York, the new laws establish an Air Pollution Control Authority, Commission, or Board within the State health departments. In Massachusetts, the law places authority in the State Department of Public Health without the creation of any special boards or commissions. In California, the law authorizes the State Department of Public Health to maintain a program of air sanitation consisting principally of surveillance and extension of technical assistance.

The laws of Massachusetts, New Jersey, New York, and Oregon give the State agency power to promulgate rules and regulations related to the control of air pollution throughout the State, and to outline procedures for dealing with violations. In addition, in Massachusetts, rules and regulations may be promulgated by the State agency for application in a specific town only; a similar provision in the New Jersey law permits the State agency to promulgate rules and regulations specifically for controlling air pollution in those areas of the State which have pollution problems. The recently enacted legislation of the State of New York provides for a 2-yr. period of study of the problem by the Air Pollution Control Board prior to promulgation of rules and regulations or codes. In each of these States, although the health department administers the law, that agency is not limited to considerations of the effects of air pollution on health.

The Massachusetts and New Jersey laws deal with the relationships between the State agency and local governmental units in some detail. In Massachusetts, municipalities are authorized to regulate air pollution within their respective boundaries, with the rules and regulations subject to review by the State Department of Public Health. The New Jersey law charges the State agency to *organize a county air pollution control association* in each county where it is considered advisable.

Interstate Compacts

In many areas air pollution problems involve 2 or more States and another device of government is necessary to achieve the desired results. The device is one provided in Article 1, Section 10, Clause 3, of the United States Constitution, the **Compact Clause.** This clause reads *no State*

shall, without the consent of Congress, enter into any agreement or compact with another State, or with a foreign power.

We have available to us a mechanism for positive cooperation among the States of the Union through the compact clause. We are experiencing a growing need for joint State action to meet problems that, although local in character, are beyond the jurisdictional reach of any one State. Although we will deal principally with the interstate compact arrangement, other means of cooperation among States are also available such as the uniform law, the reciprocal law, and the administrative agreement.

The essential elements of the interstate compact are:

a. It is formal and contractual.

b. It is an agreement between the States themselves, similar in content, form, and wording to an international treaty, and usually embodied in State law in a separate document called the *compact*.

c. In certain cases, consent of Congress is necessary.

d. The compact takes precedence over ordinary State statutes.

e. It can be enforced by suit in the Supreme Court of the United States.

In 1935, Congress approved an interstate compact between the States of New York, New Jersey, and Connecticut for the purpose of abating existing water pollution in the waters around New York Harbor. Pursuant to the compact, the 3 States set up the Interstate Sanitation Commission. On August 3, 1956, Congress, by joint resolution, amended its earlier action and consented to the States of New York, New Jersey, and Connecticut conferring upon the Interstate Sanitation Commission the power to make studies of smoke and air pollution within any and all of the territory served by the Commission. (Connecticut, the third party to the original compact, agreed to the study by the Commission provided it did not become financially liable for such undertaking.)

This is a historic step in that it is the first time a number of States acted together through the means of interstate compact to study a common air pollution problem.

Conclusion

Experience in the operation of air pollution control programs reveals the need for developing ordinances which meet the needs of the area of jurisdiction rather than the adoption of so-called model air pollution ordinances.

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A Method of Estimating the Field of Instantaneous Ground Concentration From Tower Bivane Data*

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There are a number of formulae available [Sutton or Bosanquet and Pearson] to estimate the time mean ground concentration from an elevated source. Numerical evaluation of these formulae requires determination of 2 or 3 parameters which are rather poorly defined functions of atmospheric conditions. From an applied point of view, estimates of the field of quasi-instantaneous ground concentration are of greater practical interest than are estimates of the 1 or 2 hr. mean concentration.

The purpose of this paper is to present a simple hypothesis enabling one to estimate the field of instantaneous concentration close to the source from tower bivane data. The field of instantaneous concentration is then meaned over a period of 1 hr. and it is shown that these time mean concentrations yield about the same results as a Sutton or Bosanquet type formula.

A large part of the observational material presented here was taken at Buchanan, New York, under the sponsorship of the Consolidated Edison Co. of New York. The terrain is quite rugged and the meteorological condition which interested us most was strong wind flow over a 900 ft. ridge 2 miles to the west of our site. This condition was considered critical since the effluent from the proposed stack had considerable buoyancy which would prevent ground contamination in light winds.

The hypothesis presented in the following sections is considered to be applicable to strong wind speeds only since little observed data is available for low winds and it is felt that convective and other effects may seriously disturb the bases upon which the hypothesis rests.

* Presented at the 50th Annual Meeting of the Air Pollution Control Association held at St. Louis, Mo., June 2-6, 1957.

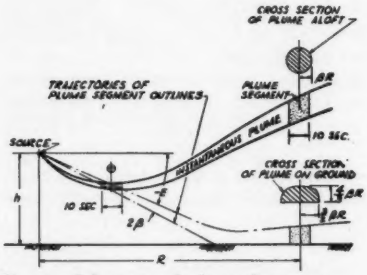

Fig. 1. Schematic of plume dimensions.

Hypothesis

Photographic observation of a cold smoke emitted from an elevated source strongly suggests that the behavior of the plume in a vertical plane can be described by 2 essential processes. The first of these is the location of the instantaneous centerline of discrete plume segments in the xz plane; the second is the local expansion of the plume around its instantaneous centerline. Fig. 1 is a sketch of the processes assumed to be acting and describes the coordinate system used.

The essence of the hypothesis presented herein is that the translation of plume segment centerlines is governed by eddies whose characteristic period is on the order of 10 sec. while the local rate of expansion of the plume around its instantaneous axis is governed by high frequency eddies whose characteristic periods are much less than 10 sec.

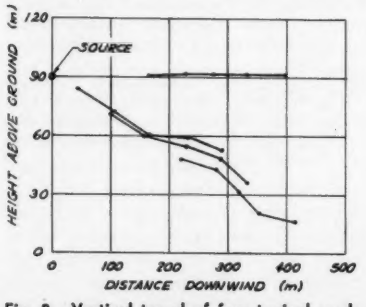

Fig. 2. Vertical travel of four typical smoke puffs in 10-sec. intervals.

Distribution of Plume Segment Centerlines

We first treat the position in space of the centerlines of smoke plume segments. The observational material consists of smoke photographs taken at 10 or 20 sec. intervals from about 5000 ft. normal to the mean wind. In Fig. 2 we have plotted the centerline of identifiable portions of a smoke plume as a function of distance downwind. The data points were taken from photographs 10 sec. apart. It is evident that a straight line connecting these points can reasonably be made to pass through the source. This suggests that a knowledge of the initial vertical orientation of a plume segment is sufficient to specify the position of the segment up to about 2000 ft. from the source, which is the effective limit of our observations.

This type of motion is also apparent from the smoke plume motion pictures made at Brookhaven. When run backward the smoke appears to move back to the origin in straight lines. The observed quasi-linearity in the xz plane implies that

$$(1)\quad \frac{D}{Dt}\left\{\frac{w}{V_2}\,(O,t_n)\right\} = \frac{D}{Dt}\left\{\tan E\,(O,t_n)\right\} \sim 0$$

where w is the mean 10 sec. vertical velocity at the origin, V_2 is the equivalently averaged horizontal velocity, E is the elevation angle of the bivane, and t_n is a successive 10 sec. time increment. As long as equation *(1)* holds true the vertical position of the center of a plume segment is given simply by

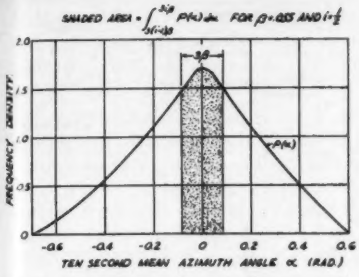

Fig. 3. Typical azimuth angle frequency distribution for lapse condition $\bar{U} = 10$ m./sec.

$$(2) \qquad Z = \int w dt = \int \frac{w dR}{V_z} = R \tan E\,(O, t_n)$$

where R is the radial distance from the source. For a source of height h the centerline of a segment will intersect the ground when the radial distance from the source is

$$(3) \qquad R = -h \cot E\,(O, t_n)$$

The longitudinal distribution of points of impact is given essentially by the probability distribution of cot E (O, t_n). An assumption similar to *(1)* for the lateral direction (not confirmed experimentally) leads to the conclusion that the points of intersection of the centerlines along a fixed arc will be distributed according to the probability distribution of sin α, or for small angles simply α. Here α is the deviation of the 10 sec. mean azimuth angle from an hourly mean α, assumed to be zero. We will make the further assumption that $P(\alpha)$ for any group of elevation angles is identical with $P(\alpha)$ for the entire range of E observed during an hour's run. An example of such a distribution is given in Fig. 3.

Local Plume Expansion

So far we have been dealing with the motion of fictitious points. We now deal with the expansion of the actual plume. Fig. 4 is a plot of the vertical width of the plume meaned at fixed distances downwind from the source as measured from sequences of photographs under a variety of wind conditions. It is evident that in the mean the local rate of vertical expansion of the plume is a linear function of distance downwind. Photographs from below the plume taken at 100 ft. and at 1000 ft. downwind indicate that the lateral dimensions of the plume are about the same as the vertical dimensions. Assuming for simplicity that the concentration is uniform on any cross-section the instantaneous concentration in the plume is

$$(4) \qquad c_i = \frac{Q}{\pi r^2 U} = \frac{Q}{\pi (r_o + \beta R)^2 U}$$

where r_o is the value of the extrapolated half-width at R = O, and β is the half slope (in radians) of the curves shown in Fig. 5. R is the radial distance from the source, and Q is the source strength.

The lower edge of the plume will strike the ground when

$$(5) \qquad R = -h \cot (E - \beta)$$

and the instantaneous concentration at the point of striking the ground is

$$(6) \qquad c_i = \frac{Q}{\pi [r_o - \beta h \cot (E - \beta)]^2 U}$$

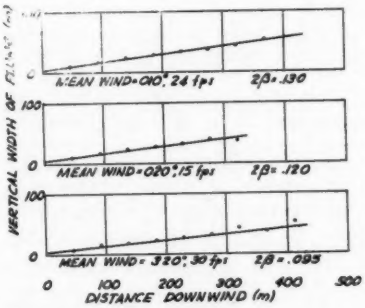

Fig. 4. Local rate of expansion of instantaneous plume.

Here h is the height of the source. An average value of β for all test conditions is seen from Fig. 4 to be of the order of 0.055 rad.

After the segment touches the ground we assume that diffusion continues at the same rate as in *(4)*, but that the cross-section of the segment changes shape. One possible shape which retains the same average concentration is a semi-ellipse with major axis on the ground, and with major and minor radii equal to $\frac{3\beta R}{2}$ and $\frac{4\beta R}{3}$ respectively. This implies a spreading of the plume to a width 50% greater than it would have at this distance aloft; although the concentration would be the same as given by *(4)*.

Mean Concentrations

It is a consequence of the above assumptions that the time history of instantaneous concentration at a point on the ground will be a sequence of step functions of constant amplitude. The total time during which the point will experience this concentration depends on the probability distributions of E and α.

Using small angle approximations, the fraction of the total number of emitted plume segments which will cross a fixed arc on the ground at a distance R is given by

$$P\left[(E - \beta) < \frac{h}{R}\right]$$

which is obtained from the cumulative frequency distribution of elevation angles. Examples of such cumulative frequency distributions are shown in Fig. 5 for typical atmospheric conditions as observed at Buchanan. Experimental evidence indicates that the velocity of these plume segments after contact with the ground will be about ½ of the mean wind speed which exists at the point of emission (300 ft.). Therefore, the fraction of time that the segments will be crossing this arc will be

$$(7) \qquad 2P\left[(E - \beta) < -\frac{h}{R}\right]$$

Of the total time which all points on the arc detect smoke, a fixed point will be exposed a fraction equal to $\int_{3(i-1)\beta}^{3i\beta} P(\alpha)\,d\alpha$. This is the area under the $P(\alpha)$ curve (Fig. 3) over a width of α equal to 3β. The index i may assume any value. The maximum value of the integral is obtained when i = 0.5. Typical values for various atmospheric conditions and $\beta = .055$ are shown on the following page:

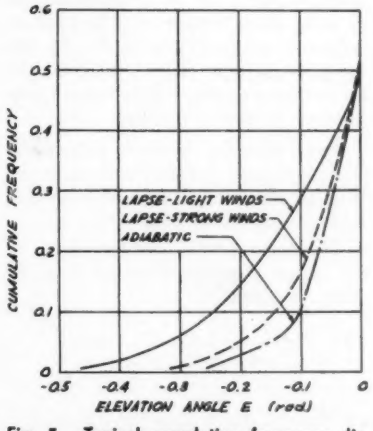

Fig. 5. Typical cumulative frequency distribution of elevation angles.

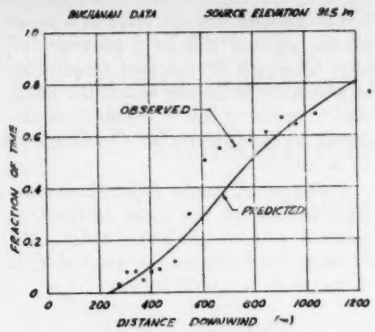

Fig. 6. Comparison of observed and predicted duration of smoke on ground.

	$\int_{-1.5\beta}^{1.5\beta} P(a)\,da$	$\sigma(a)$ (rad)
Lapse Light Winds	0.18	0.35
Lapse Strong Winds	0.25	0.26
Adiabatic	0.40	0.16

The time mean concentration at a point on an arc R distance downwind is given by

$$(8)\quad \bar{c} = 2P\left[(E-\beta) < -\frac{h}{R}\right] \cdot \int_{3(i-1)\beta}^{3i\beta} P(a)\,da \cdot \frac{Q}{\pi (r_0 + \beta R)^2 U}$$

It will be noted that for large distances from the source, the first factor in equation *(8)* approaches a constant and the mean concentration thereafter is proportional to $\frac{1}{R^2}$. The cross-wind distribution is given by the statistics of the second term. Since, by hypothesis, the distribution $P(a)$ is independent of E or R, the σ of the ground concentration is proportional to R. In this form, equation *(8)* resembles the Bosanquet-Pearson solution more than it does the Sutton solution.

The downwind location of the point of maximum mean concentration may be obtained most easily by numerical evaluation of $\bar{c}$ versus R.

The ratio of the instantaneous to the mean concentration at a given point is given by

$$(9)\quad \frac{c_i}{\bar{c}} = \frac{1}{2P\left[(E-\beta) < -\frac{h}{R}\right]} \cdot \int_{3(i-1)\beta}^{3i\beta} P(a)\,da$$

This ratio may assume values between 2 and 4 for large values of R with $i = \frac{1}{2}$ and approaches infinity for small values of R or large absolute values of i.

Verification of Hypothesis

Several comparisons were made between the results predicted by the hypothesis and observed data or other theoretical predictions.

(a) Consecutive photographs of smoke being emitted from the top of the 300 ft. tower at Buchanan permitted the calculation of the fraction of time the smoke was seen to be on the ground at specified distances downwind from the stack. The equivalent time fraction is predicted by the hypothesis as given by equation *(7)*. Fig. 6 shows the observed and predicted values for the strong wind lapse case (average of 66 photos in two 11 minute series). The predicted values were calculated from the cumulative probability distribution of E shown in Fig. 5 with $R = \frac{-h}{(E-\beta)} = \frac{91.5}{(E-.055)}$. The agreement is fair, considering the limited number of smoke observations and the possibility of misinterpretation of the smoke outline in the photos.

(b) The predicted time mean concentration may be compared with that of Sutton. Assuming $r_o = 0$ in equation *(8)*, we obtain with $i = \frac{1}{2}$

$$\frac{\bar{c}\,\pi\,U}{2\,Q} = P\left[(E-\beta) < -\frac{h}{R}\right] \cdot \int_{-1.5\beta}^{+1.5\beta} P(a)\,da \cdot \frac{1}{(\beta R)^2}$$

Fig. 7 shows curves of this quantity for a typical 4 mph. lapse condition, a typical 22 mph. lapse and an 18 mph adiabatic condition. The first term was computed from the appropriate frequency distribution (Fig. 5) using $h = 91.5$ m. and $\beta = .055$. Values of the second were taken from the table above.

We show the light wind case merely to demonstrate that the location of the maximum is reasonable; it is probable that β is greater for the light wind case than assumed. The point of maximum concentration is

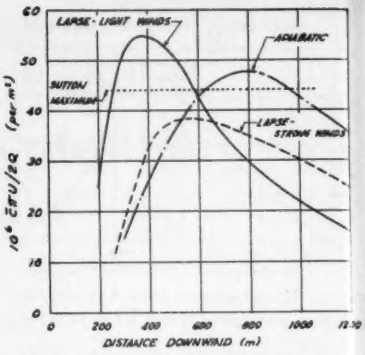

Fig. 7. Curves of mean axial concentration for typical atmospheric conditions.

close to the source for the light wind lapse and moves farther downwind as the wind speed increases or as the temperature gradient approaches the adiabatic. This is what is traditionally expected. The equivalent Sutton equation for maximum mean concentration is

$$\frac{\bar{c}\,\pi\,U}{2\,Q} = \frac{1}{e\,h^2} \cdot \frac{C_z}{C_y}$$

Assuming $\frac{C_z}{C_y} = 1$ and $h = 91.5$ m. yields a value of 44×10^{-6} which lies in the neighborhood of the predicted maxima.

(c) It would be desirable to check the instantaneous concentrations predicted by the model. Unfortunately, the only concentration traces available to use under strong wind speed lapse conditions are for distances of 2000 and 2800 m. from the source. We have plotted one such trace (Fig. 8) obtained at 2800 m. from the source which the meteorology group at Brookhaven has kindly provided. It may be seen that the peak concentrations tend to reach the same values time after time. Assuming that β at Brookhaven is the same as at Buchanan (0.055 radians) and $r_o = 4$ m., the instantaneous concentration predicted by the present model (with $Q = 44$ gms./sec., $U = 10$ m./sec.) is 56×10^{-3} mg./m.^{3} which compares rather well with the observed peaks of about 60×10^{-3} mg./m.^{3}.

The predicted time mean concentration may be obtained from equation *(8)*. Since the distance is rather large it is safe to take

$$2\left[P(E-\beta) < -\frac{h}{R}\right] = 1,$$

the integral $\int_{-1.5\beta}^{1.5\beta} P(a)\,da$

is about 0.35 at Brookhaven, and the mean concentration is therefore about .020 mg./m.^{3} compared to the observed value of .018 mg./m.^{3}

Such good agreement at large distances from the source is a little surprising since we would not expect our assumptions to be valid at great distances from the source. To set the record straight, the other set of data taken at 2000 m. downwind at about the same time indicates that our model overestimates both the instantaneous and mean concentration by a factor of 3. It is difficult to reconcile the two densitometer traces since the maximum concentration at Brookhaven generally occurs at about 700 m. for their B_1 case while for the 2 traces on hand the 2800 m. station has a greater mean concentration than the station at 2000 m. In any event, since the same factor applies to both mean and instantaneous concentrations, our model predicts the per cent time substantial amounts of smoke was on the ground correctly for both cases.

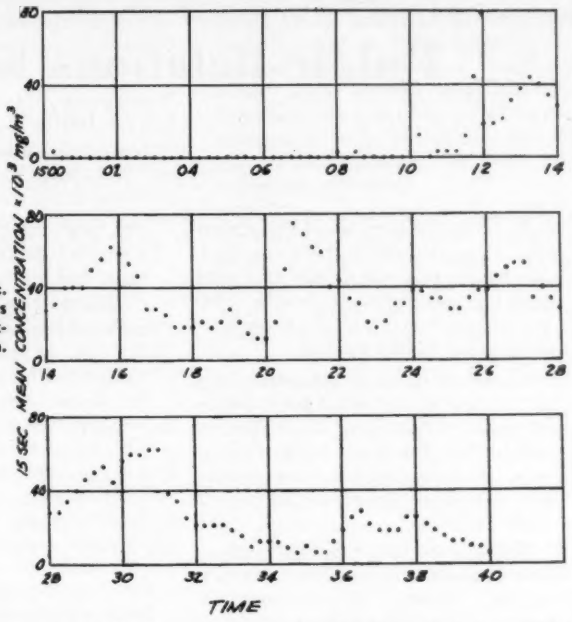

Fig. 8. Fifteen sec. mean concentrations according to Brookhaven. R = 2800 m.

Conclusion

The very simple model presented in this paper seems to yield approximately the correct gross results for the mean concentration close to the source under strong wind speed conditions and therefore inferentially yields instantaneous concentrations which cannot be too greatly amiss. The parameters defining the distribution of smoke on the ground are directly observable from tower observations, while the parameter which determines the concentration value, β, is directly observable from smoke photographs. The concentrations are rather sensitive to β values and introduce a factor of 2 as β varies from .05 to .07.

Extension of the present model to cover the case of non-uniform concentration distribution would result in a more realistic form for the instantaneous concentration.

For greater distances downwind, the effect of plume width becoming greater than the characteristic vertical length of an eddy should be considered as well as the loss of correlation in the azimuth of the plume trajectory.

Acknowledgments

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Public Relations for the APCA Member*

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It is not the purpose of this discussion to glorify public relations, or to put haloes over the heads of professional public relations people. Nor are we concerned with the theories of influencing public opinion.

Public relations is something you, as members of the APCA have, whether you want it or not. If handled intelligently it can work to your advantage, if disregarded it can develop into a serious obstacle to success in your field.

The job ahead for public relations may be more important than we now realize. America is a growing dynamic country. We are a restless people. There are those who feel that *big business* is anti-social and should be *controlled*. We are members of a *control* association.

The 50 year story of the Air Pollution Control Association is the story of the hopes and accomplishments of 100,000 men (and women) in this country. It is the story of service to the public and industry that is hard to equal in history. It can be told best by each member showing as effectively as he knows how, what he is doing to make this country a better place in which to live.

The term *public relations* is not simply a synonym for publicity. It consists, first of all, of doing the right thing and letting people know about it. It is not a job which could be left to a few professional people. It is everybody's job in general, and as members of the Air Pollution Control Association it is your job in particular.

Many business men (and individuals) measure values in solid dollars and for good reason. Good will however is usually carried on the books by the accountants as a one dollar item. Salaries are normally paid on the basis of *the number of statistical reports that are turned in* and *number of miles traveled*.

Good will is worth much more than a dollar, it is not so difficult to measure, and for this reason we should avoid this depreciation on the balance sheet and in the payment for services.

Here is a *for instance*, a small but nationally known manufacturing plant in New England burned to the ground. The plant, the equipment, the inventories, and the company's business records were a total loss. There was a little insurance to cover the loss, but not enough to get the business going again. With accounts receivable records gone the one tangible asset upon which money could be borrowed was also gone. It was a discouraging situation for the three brothers who owned the business.

Fortunately over the years the owners had earned a reputation for being honest. They had always paid their bills promptly. They treated their employees well and their employees liked their jobs. The suppliers valued their business. They were respected by their customers. They did have an asset which was not shown on the books.

As a result of the good opinion held by members of this community for the owners, a one and a half million stock issue was quickly over-subscribed locally. They were back in business. In spite of a complete loss good will was the one intact asset.

Good public relations does not require a million dollar budget. It can be the result of many small things as well as the result of strategically planned projects. What you do, may be the thing to do, and may be well done. On the other hand it may be the subject of misunderstanding and misinterpretation. Therefore the *doing*, while important, is not enough. With doing you must obtain understanding and with understanding you sell yourself and your method of operation.

An air pollution control officer in order to be effective must be skilled not only in the technology of the field, but in public administration, in community leadership, and face to face dealings with representatives of government, other governmental agencies and divisions, business and industry at all ranks and stations.

What Is The Problem?

It has been said that the biggest single problem in the field of air pollution control work today is that salaries and prestige levels of control officials are too low.

To hold and attract top caliber air pollution control men will benefit the community. To so benefit the community requires the honest earning of public understanding, acceptance and support. The net result will be to lower the total cost of air pollution control to the community. To earn the net result requires positive action on the part of each member of this Association. As the accepted professional authority in the field we should be willing and expert at providing accurate and understandable information to the public, industry, business, local government, and to the newly-budding agencies coming into the field.

How Is The Job Done

A good way to make a start is to determine the need. This is not the need for information, but the need for *what* information. It is a rather simple procedure. The method is simply to get objective opinions. Three methods follow:

1. Determine the opinions of how effective the air pollution control program is, as expressed by members of the city administration and employees;
2. Determine the opinions of the man on the street, in addition to the merchants, the industrial managers and home owners;
3. Determine the attitude of people generally by person-to-person questioning of those who formulate public opinion in the community, such as newspaper editors, teachers, the clergy, and political experts.

This information can be obtained by informal discussions on an individual basis. In large areas the base can be broadened by obtaining the cooperation of university instructors,

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aided by their students or by the assistance of serious high school organizations. The opinion gathering need not be and should not be a *drive* or *concerted effort* and does not require publicity.

The very fact that you are making a survey or have made a survey is the evidence of your interest in your community and the opinions of the community. This is a start in good public relations. A careful analysis of the needs for information should be made and a personal strategy worked out for gaining understanding of the problems exposed. A willingness to share these results can be an important factor in itself and can serve as a useful public relations tool.

Now let's take a look at analysis of the need for information and the aside remarks on what public things we are doing in the way of an effective job. The classification headings of the analysis will probably best be grouped under the following descriptions:

1. What air pollution control?
2. Are you kidding?
3. You stink.
4. A very slight improvement has been made.

Although there is always a slight tendency for us to agree with those who agree with us, avoid this pitfall. The most severe critics are your best friends. The most stupid criticisms are your most valuable tools. The objective is not to prove that you are right. The objective is to obtain understanding and gain cooperation. As difficult as this may seem, it can be done.

Barriers to Good Communications

Good communications require the elimination of several barriers. One barrier is the lack of mutual understanding between people. The difference in background, ambitions, and motivations create mental blocks to what you have to say. You do not have to change your own background or motivations, but it helps to understand the other fellow's. So it helps to listen.

The second barrier is that the usual means of communication may not be logical at all. The word *smoke* for instance, may have 15 meanings to 15 different people. So try to understand what your critic means when he uses words, — *his* words, not your words.

Another barrier is the failure to listen intelligently. Communication does not exist on a one way street. If you are framing an answer or rationalizing while you listen, you are not getting results.

Probably one of the greatest barriers to understanding is the so-called method of using formal communication. Forms to fill out, channels to go through, organization charts to show the channels to go through, are all devices used to obtain lack of understanding.

The man who is insecure insists on formal channels of communication and having done so is secure and ineffective on the lower rung of the totem pole.

Far more simple, effective and positive, is the informal method. The man who needs the information gets it directly from the man who has it. You have the information, and the public needs information. What can be done?

Methods of Communication

The positive approach is to use the successful known methods of communication. They have been developed for almost any known situation. Your main problem is to select those that suit your personality and your particular need.

Public Talks and Appearances

Any member of the APCA who is not willing and able to get up and make an extemporaneous talk on what he's doing for the community is not worth his pay. With patience and practice any person can become a better than average speaker. In nearly every community there is some facility for personal improvement in making a public talk. Usually there are local toastmasters groups or courses in public speaking. Membership in these groups gives the confidence any speaker must have to make the desired impressions on an audience and to put his story across most effectively. If for no other reason, such preparation will arm you against those speakers who have nothing to say and do not know how to say it.

A little practice goes a long way. It is well to start with small groups and over a period of time build up to larger audiences. The subjects should be selected with consideration for the group interest. A talk to a business group might be handled entirely different than a talk to a student or teacher group. A presentation of *City Air Pollution Control* would be excellent for groups like Kiwanis, Lions, Rotary Clubs, Chambers of Commerce, men's business organizations, American Legion Posts, and other local service organizations. Since you are providing a real service to the community, the possibilities for explaining this service in their language are unlimited.

For parent-teachers associations, high school groups, vocational counsellers and groups interested in opportunities for young people, the subject of *A Career in Air Pollution Control* would be of extreme interest. Garden groups and women's clubs would be interested in *Air Pollution Control and Plant Life.*

While the programs of many Women's Clubs are cultural and social, women are increasingly civic-minded and are extremely important from a public relations standpoint. Many of these organizations have specific programs planned on a yearly basis and depend on outside speakers for worthwhile causes.

Personal contacts through friends will find out what the groups are particularly interested in. A well-composed letter offering a few constructive suggestions instigated by unselfish motivations will prepare the way for invitations. If you have developed an effective talk which has been made a number of times so that you are able to deliver it dramatically, you will be hard put to keep up with the demand.

There are more books written on effective speech making than there are members of the APCA. All of them have good points, but most of them forget this most important point. When a salesman is through with his presentation he asks for the order. When a politician makes a talk he asks for the vote. When you finish your talk to your audience don't forget to tell them what you want them to do. And in good faith find out what they want you to do.

Audio-Visual Aids

The sound-motion picture has become one of the most important tools in positive communications. Unfortunately the cost of producing a good sound-motion picture of 20 to 30 minutes duration may run from $15000 to $30000 and this limits the production to a few of the larger cities or industrial operations.

An excellent and inexpensive alternative is the use of colored slides with a simple projector and screen. Every APCA member should be

equipped with a 35 mm. camera and color film and consistently log the conditions, the installations, and the before and after effects of their work in Air Pollution Control. This visual story of the progress made in the respective community has a terrific and dramatic impact. The visual method tells a story in seconds while voluminous written reports may never see the light of day.

Press Relations

In building good press relations it is important to become acquainted with members of the working press—managing editors, — city editors, columnists, reporters and photographers. A good way to get acquainted is to invite them out to see the work you are doing, the installations, the before and after effect. They are interested in getting air pollution control news since it is good news for the community.

The editorial good neighbor policy pays dividends. The press is close to public opinion and when trouble is brewing a cooperative press will ask you for an explanation. When they do, — give them all the information you can, consistent with the interests of the principals involved. Newsmen are under pressure to get facts and they appreciate cooperation. Generalities and evasiveness are road blocks to public relations and should be avoided.

Publicity Releases

Directed to the right editors the neater and simpler the news release appears the more chance it has of being read and put to use. A title gives the editor a clue as to contents, although it probably won't be used. A standard size sheet 8½ in. by 11 in., double-spaced and plain white helps. Your name and title should be at the top. The date written and day to release is required.

The who, what, when, where, why and how belong in the first paragraph. Details can follow. These *do's* and *don'ts* help:

Do

. . . put in all the pertinent facts. The editor will cut the story.

. . . learn when the paper goes to press and get in story a day or more ahead.

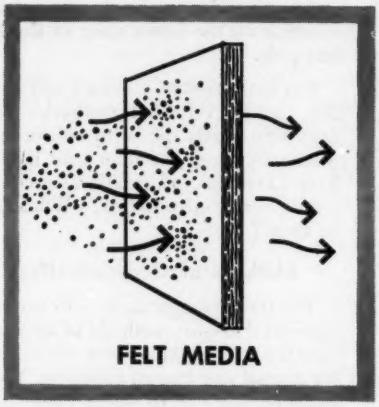
. . . get the names, dates and statistics complete and correct.

Don't

. . . submit a story after the event takes place.

DAY

DUST CONTROL NEWS



Here's why felt filter media traps dust BETTER!

This magnified view of filter media makes it easy to see why felt is more efficient than woven cloth. With cloth, the average opening between thread strands is above 10 microns. Felt, however, is made up of closely matted fibres and the air travels a tortuous path between the thousands of individual fibres. For all practical purposes, the resistance of these media is the same. That's why felt filtering media (wool or synthetic) is used exclusively in *all* filters made by DAY.

Consider this important fact. What happens when these two media are cleaned? Woven cloth is cleaned by shaking, rapping or low velocity reverse air. In many cases woven cloth is overcleaned, permitting leakage until openings between strands are again plugged with dust. The overall performance is one of erratic back pressure and filtering efficiency. *With DAY filters the porosity of the felt media is maintained by automatic counter flow air. Back pressure doesn't vary and peak filtering efficiency is constantly maintained.*

Whether your problem is collecting and recovering valuable dust or controlling dangerous or obnoxious dust; write for our free bulletin "DUST FILTER FACTS." Read this bulletin carefully before you decide on *any* dust filter. It contains useful charts and air engineering data. It also contains more information about the many services and equipment available from DAY. Write toDAY for Bulletin F-75.

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Representatives in Principal Cities

EQUIPMENT ONLY OR A COMPLETE SYSTEM

. . . ask the editor to print a story as a favor.

. . . editorialize or try to give advice to the public.

When submitting photos have them made by professional photo-journalists.

It is not necessary to wait for perfection to tell the air pollution control story. Progress is also good news.

Visiting Officials

Occasionally invite APCA officials from other cities to visit your city or plant and when they arrive arrange a lunch with several prominent citizens. The local press will usually cover such meetings and may send a photographer.

When a local industrial operation has completed an air pollution control application, arrange to have the company invite some of its out-of-town officials in addition to out-of-town control officials and repeat the process. It is well to brief the visitors for an interview and if the visitors can sincerely compliment the community on the progress made, the story may make the front page.

History Of Your Work

The 50 year history of the Air Pollution Control Association will make a great public relations story when it is put together. On the other hand you should not wait 50 years to put together the history of the work you, your city, or your company has done in the field of Air Pollution Control. Every public service has something worthwhile in its history that merits publication. Such a record, in mimeograph or booklet form is a useful public relations tool. Made available in the technical, business, and school libraries it can be useful as a reference work. It is a handy reference and guide for visitors and extremely useful for budget purposes.

Service Clubs and Civic Organizations

The idea of leadership through service to others is a definite concept of service clubs and civic organizations. The Rotary, the Kiwanis, the Lions, the Optimists are all active organizations dedicated to the idea of serving the community. The important committee of the service club is the program committee. This committee not only arranges for the major activities, but also makes rec-

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ommendations to the board for major activities which the club might undertake.

The most important local civic organization, from a public relations standpoint, is the Chamber of Commerce. Many commerce chambers are interested in attracting industry or improving slum areas. Membership in these organizations and active participation in committee planning is a must for the alert APCA official or member. Some of these groups have done an outstanding job with the Cleaner Air Week program and Cleaner Air Activities are a part of the overall program of most service organizations.

The key to good relations with the community is simply being a good citizen. To be a good citizen the APCA member should participate in civic affairs, belong to and be active in business and service organizations, cooperate with local authorities on community wide problems and participate in local government.

Measuring Community Acceptance

Indications of acceptance to specific programs are apparent if looked for. It is important to know what those who influence public opinion in the community think about your program. These people are usually present at luncheon clubs, church affairs, business meetings and similar affairs. By adroit questioning it is not difficult to find out the state of affairs.

Editorials that appear in local newspapers are another indication of community acceptance. Newsmen are conscious of what interests readers. When readers are interested in your field it will receive treatment. Clippings should be kept and reviewed.

Invitations to community affairs are an index of acceptance by members of the community and participation generates invitations.

In measuring community acceptance take every opportunity to write letters of courtesy. This keeps your name and the name of the Agency before as many people as possible in a pleasing manner.

Another important group in formulating public opinion at the grass roots level are the local barbers, tavern keepers, and taxi-cab drivers. Their observations may be picturesque but are certainly valid and most important.

Summary

Significant as any indication of good performance may be there is no substitute for personal performance. Not all the good that is done is immediately apparent. Some heat as well as smoke goes up in the chimney. In time the good work will be known and that is the real objective.

In the final analysis public relations consists simply of doing the right thing and letting people know about it. Without letting people know about it, you may receive your reward in Heaven. The use of modern good will building methods speeds the process and widens your horizons, in addition to strengthening your balance sheet.

The Air Pollution Control Association is the accepted professional authority in the field. It is imperative for its members to be expert in providing accurate and understandable information to the community and the public. To be expert and willing requires action on your part.

The National Cleaner Air Week Committee is prepared with advertising, editorial, radio, and tv promotion materials for the 1958 Cleaner Air Week. The National Public Relations Committee has prepared a recorded interview and additional material spelling out the community approach to air pollution control. Slides, films, brochures, national articles and other aids are being prepared for your use. Make use of these aids.

Acknowledgement

The contents of this article are based on the many excellent presentations in the *Public Relations Handbook*, Aspley & van Houten, The Dartnell Corporation, and personal communications with William J. Getty, Jr., Public Relations Representative, Sun Oil Company, Don Sweeney, Public Relations Representative, Western Oil and Gas Association, Joseph R. McGinty, Public Relations Representative, United States Steel Corporation, and H. B. Brown, Jr., Public Relations Representative, National Coal Association.

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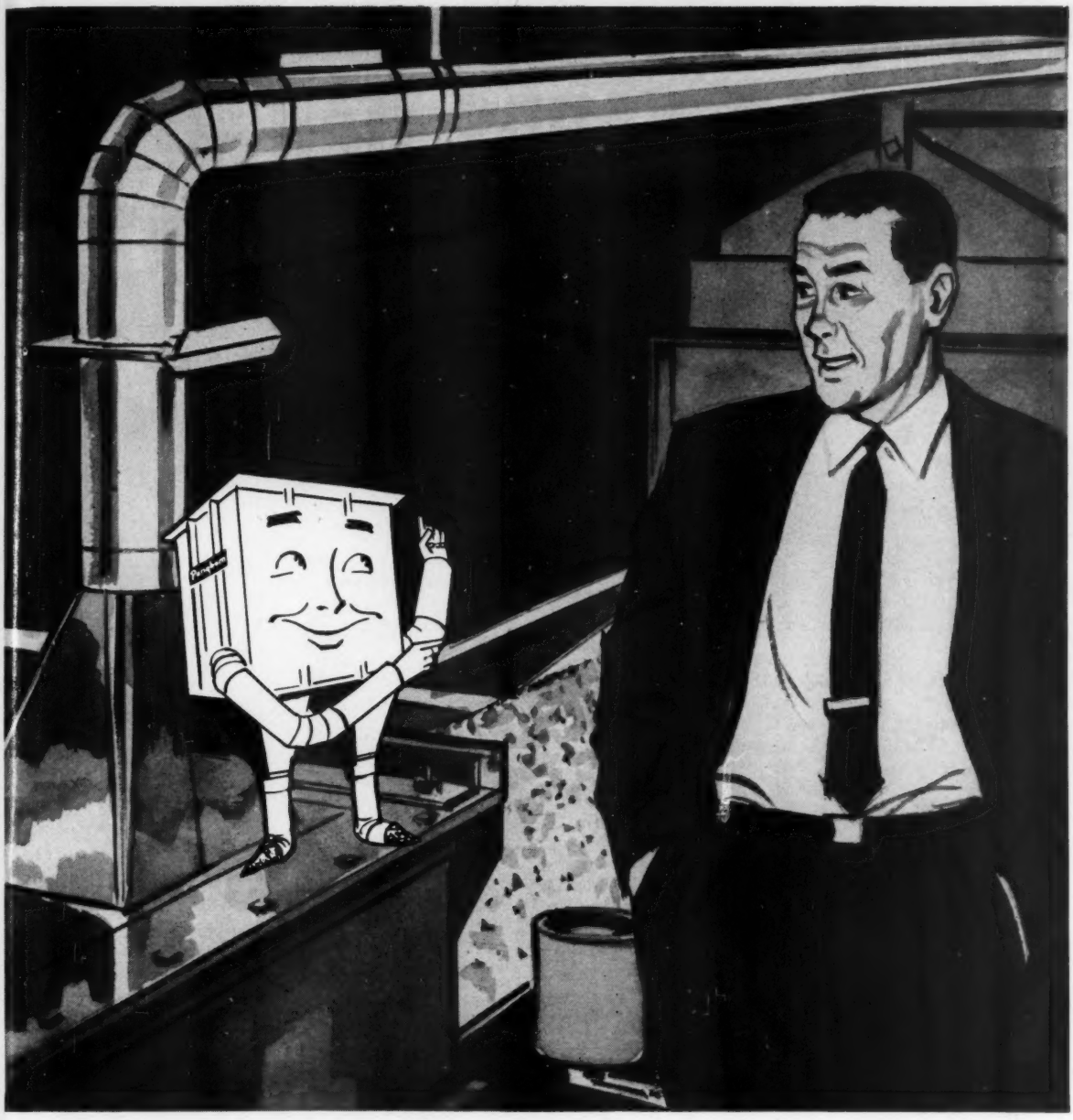

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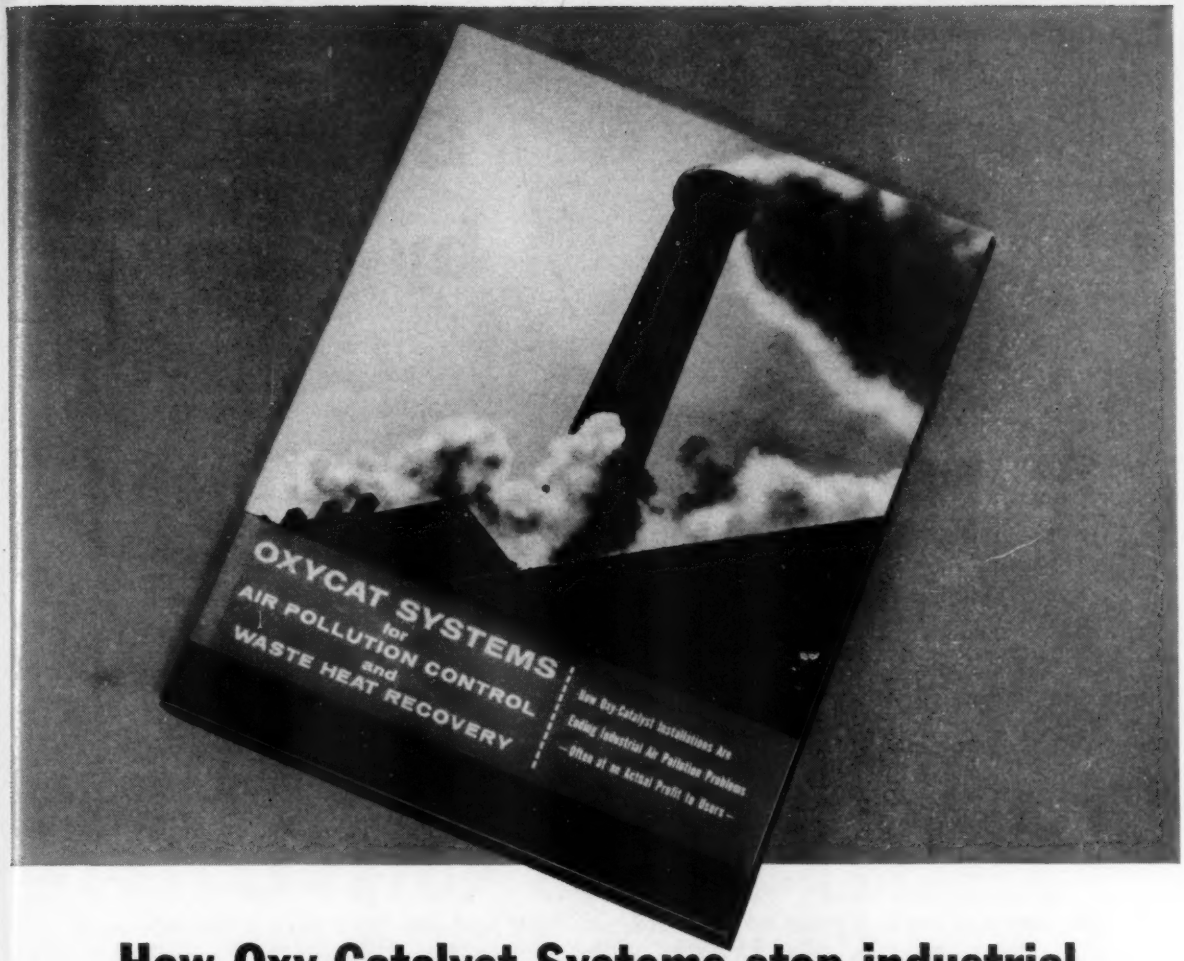

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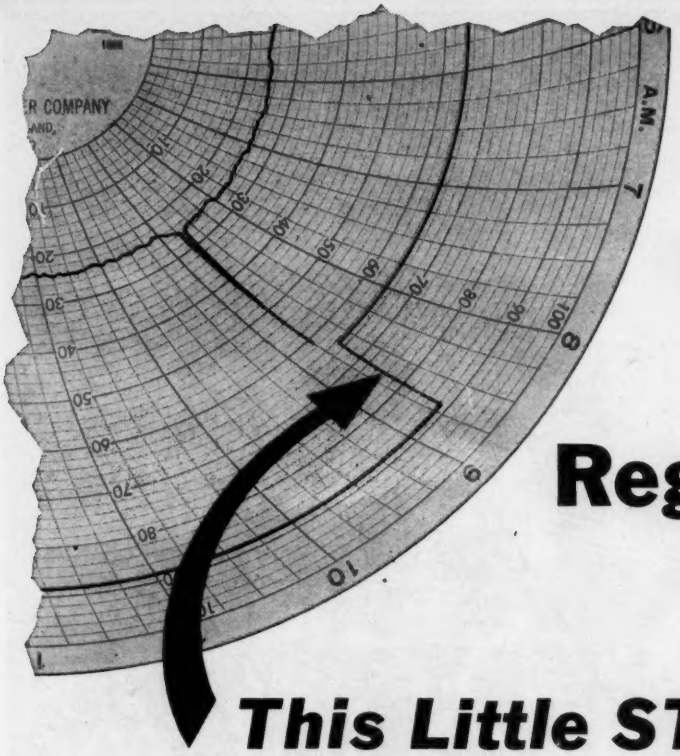

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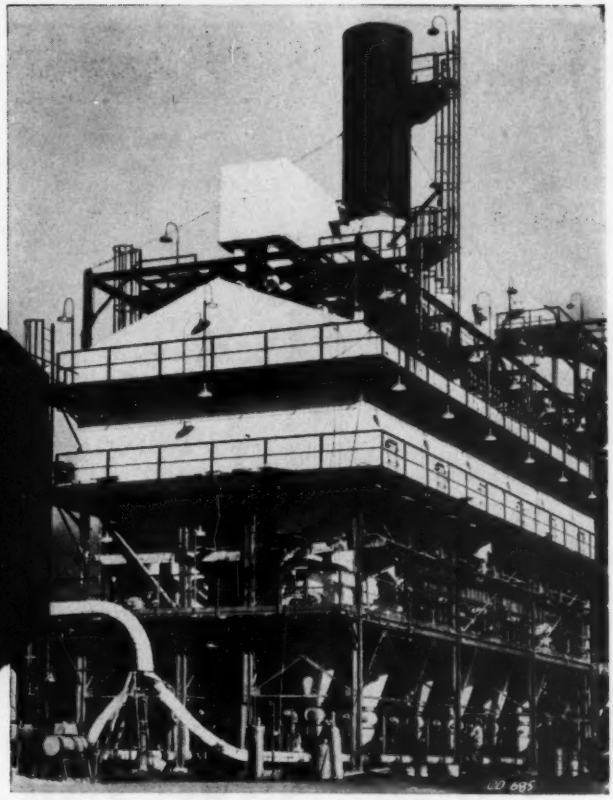

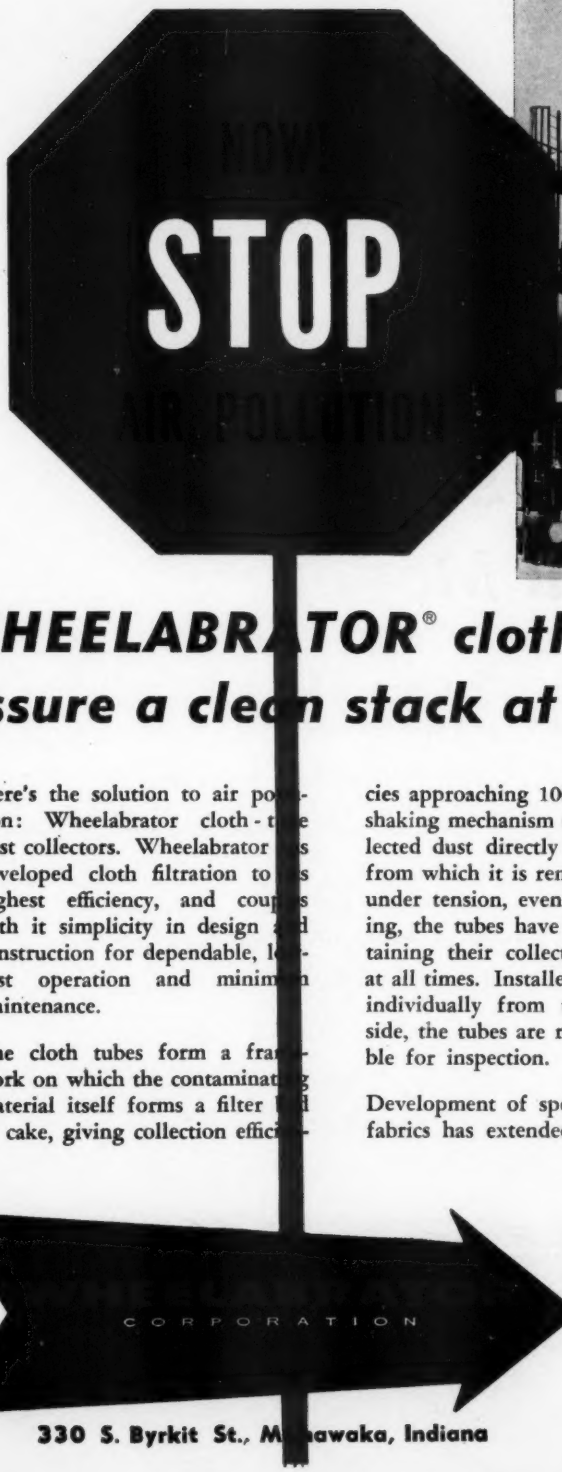

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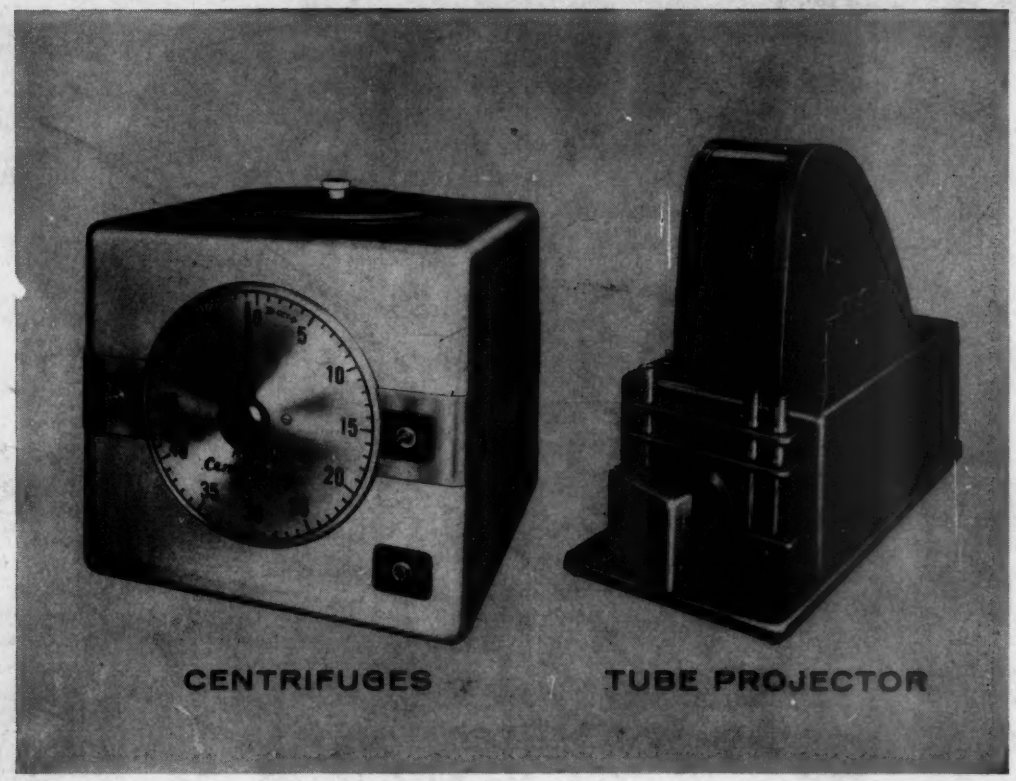

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